PHD

Supporting the Transfer of Learning of Freehand Gestures

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Award date:
2015

Awarding institution:
University of Bath

Supporting the Transfer of Learning of Freehand Gestures

submitted by

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for the degree of Doctor of Philosophy

of the

University of Bath

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June 2015

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Acknowledgements

I would like to thank everyone who has helped and supported me throughout my research. This thesis would not have been possible without you all and I am eternally grateful.

Firstly, I would like to thank my supervisor Prof. Eamonn O'Neill for all of his guidance, support, time and effort throughout the course of this research.

Furthermore, I would like thank Prof. Peter Johnson for his challenging and thought provoking conversations. My thanks also goes to Dr. Andy Ridge, Dr. David Wilson and Dr. Andrew Chinery for their mutual support throughout the writing of our respective theses. Additionally, I would like to thank all the members of the Department of Computer Science at the University of Bath and especially to all of you who participated in my studies.

I would like to acknowledge my examiners Dr. Leon Watts and Prof. Steve Benford. I really enjoyed the viva and found it such a positive experience.

Finally, I would like to thank Maria-Marina Korea for her kind words and advice, her support and her tremendous patience. Maria has been a rock of support throughout and I can not thank her enough. This thesis is dedicated to you.

To Maria - Σε ευχαριστώ ψυχή μου

Publications

Three publications have been generated as a direct result of the research presented in this thesis.

1. Michael Wright, Chun-Jung Lin, Eamonn O'Neill, Darren Cosker and Peter Johnson: *3D Gesture Recognition: An Evaluation of User and System Performance*, In Proceedings of Pervasive 2011, Springer (2011) 294-313.

2. Michael Wright, Eamonn O'Neill, Chun-Jung Lin, Darren Cosker and Peter Johnson: *Identifying, Applying and Evaluating Gestural Interaction in Ubiquitous and Pervasive Computing*, Extended Abstract presented at the 9th International Gesture Workshop, May 2011, Athens, Greece.

3. Michael Wright, Eamonn O'Neill and Peter Johnson: *A Framework for Generating Gesture Sets for Mobile Pervasive Computing*, Extended Abstract presented at the Mobile Gestures Workshop at MobileHCI, August 2011, Stockholm, Sweden

Abstract

Freehand gestural interaction, that is gestures performed mid air without holding an input device or wearing markers for tracking, are increasingly being used as an interaction technique for a range of devices and applications. Unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist are typically accomplished using a series of mouse clicks in a desktop environment, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore one of the challenges for designers, and users, is the need to support the learning of potentially large sets of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, can be transferred by the user to perform analogous tasks on different, and potentially unknown, devices and applications.

In this thesis we address this challenge answering the research question, *"how can we support the transfer of learning of freehand gestures across different devices and applications"*? Where transfer of learning is the application of knowledge learnt in one context to a new context, for example, performing previously learnt freehand gestures to interact with different devices and applications.

Drawing on previous work we develop an understanding of how designers can support the transfer of learning of freehand gestures. In particular, two mechanisms are investigated which, if supported, can facilitate transfer of learning: learning new material to automaticity and mindful abstraction, i.e. gaining an understanding of the underlying principle, technique, strategy, etc. The literature suggests that supporting both of these mechanisms can improve both the learning and the transfer of learning of freehand gestures.

Building on this understanding, a series of related studies are designed and conducted. The results of these studies inform recommendations for designers on (i) how to support both mechanisms of transfer of learning for new users of freehand gestures and (ii) the effects that supporting these mechanisms are likely to have on the transfer of learning of freehand gestures. Additionally, the results of these studies provide metrics which allow designers to predict and evaluate both the ease of learning and the ease of transfer of learning of freehand gestures.

Chapter 1

Introduction

Freehand gestural interaction, that is gestures performed mid air without holding an input device or wearing markers for tracking, are increasingly being used as an interaction technique for a range of devices and applications. For example, Chen et al. [2003]; Fikkert et al. [2010]; Kray et al. [2010]; Mistry et al. [2009], explore how freehand gestural interaction can provide users with a rich, more naturalistic, method of interaction with devices and applications in different settings and contexts. Furthermore, consumer products such as Microsoft's Kinect[1] and Samsung's Gesture Controlled TV[2] are increasingly familiarising consumers with the use of freehand gestures for interaction with on-screen displays and avatars.

Unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. In traditional point-and-click desktop interfaces, and derivative touchscreen point-and-tap interfaces, the user has available a very small set of interface actions that are used to perform a range of different tasks. Gestural interface users, in contrast, are often provided with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist is typically accomplished using a series of mouse clicks in a desktop environment, or taps on a touchscreen, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of potentially large sets of freehand gestures. This is a particular challenge for gestural interfaces as, "opposed to buttons and menus, the user cannot guess which [gestures] are available and which [gesture] triggers which command" [Appert and Zhai, 2009, p 2294].

A further challenge for designers, and users, is that there is currently no standard set of

[1] Microsoft Kinect - `http://www.xbox.com/en-GB/xbox-one/accessories/kinect-for-xbox-one` (last accessed June 2015)

[2] Samsung Gesture Controlled TV - `http://www.samsung.com/uk/discover/in_the_home/at-ces-2013-with-samsung-electronics/` (last accessed June 2015)

freehand gestures for gestural interfaces. This may lead to different freehand gestures being used for the same tasks on different devices or applications. For example, to transfer data from one device to another, Yatani et al. [2005] propose a set of toss and swing gestures and Yoo et al. [2010] propose different cocktail mixing gestures. This is a significant limitation as users could be required to learn different freehand gestures for each device and application they use.

The development of a standard set of freehand gestures could reduce the burden of the user needing to learn different freehand gestures for each device and application they use. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform analogous tasks on different, and potentially unknown, devices and applications. This transfer of learning of freehand gestures is an important challenge and one which has received little attention in the literature.

This thesis addresses this challenge. Specifically, this thesis investigates the transfer of learning of freehand gestures.

In the remainder of this chapter we present the background to this research, identifying the research questions and objectives to be addressed throughout the thesis. We report the research methodologies used as well as detailing the contributions of the thesis. Finally, we outline the remaining chapters to set the scene for the thesis.

1.1 Background

Transfer of learning is defined as the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Bransford, 2000, p15] or "how previous learning influences current and future learning and how past or current learning is applied or adapted to similar or novel situations" [Haskell, 2001, p23]. For freehand gestural interaction, transfer of learning is the ability of users to perform previously learnt freehand gestures to interact with different devices and applications.

The literature (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]) suggests that to support transfer of learning we should support two mechanisms of transfer of learning,

1. Learning new material to automaticity
2. Mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc.

Where, learning to automaticity is when "a cognitive element is learned and practiced in a variety of contexts until it becomes automatic [which] on a later occasion, in another context, the stimulus characteristics sufficiently resemble those of the earlier [...] context to trigger automatically the element" [Salomon and Perkins, 1989, p120].

Mindful abstraction is the deliberate abstraction and understanding of "a principle, main idea, strategy or procedure, which then becomes a candidate for transfer" [Salomon and Perkins, 1989, p126].

Building on this literature, this thesis investigates the transfer of learning of freehand gestures to support freehand gestural interaction across devices and applications. Moreover, this thesis investigates the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures.

Learning Freehand Gestures to Automaticity

To support learning to automaticity, the literature suggests learners are provided with opportunities for extensive practice with multiple examples in different contexts (e.g. Salomon and Perkins [1989]; Haskell [2001]; Bransford [2000]). However, Salomon and Perkins [1989] suggest that by drawing on the learners prior knowledge and experience the length of time taken to learn new material may be reduced. Similarly, Bransford [2000] highlights the role "personal, cultural and idiosyncratic experiences" play in supporting the learning of new material.

Research in human computer interaction also highlights the importance of drawing on the users' prior knowledge and experience to support the learning of new systems. Norman [2002] states that designers should "use both knowledge in the world and knowledge in the head". Shneiderman [1998], states that designers should "strive for consistency". Consistency draws the users' prior knowledge and experience of not only that particular system, but of similar systems, to support the user in learning a new system. Shneiderman suggest that designers should provide users with consistent sequences of actions, commands and terminology in, for example, prompts, menus, and help screens.

Consistency of user interaction across different systems has been shown to positively support learning. Polson and Kieras [1985] report that where new systems share large numbers of the same task structures and/or methods of interaction as other systems known to the user, the time to learn is reduced. Furthermore, Polson et al. [1986, 1987] report that consistency facilitates positive transfer i.e. where there are similarities in a task structure and/or method of interaction, users transfer these skills acquired previously to perform new tasks or interactions.

Building on this literature, we investigate how to draw on the users' prior knowledge and experience to support the mechanism of transfer of learning, learning to automaticity, for freehand gestures. Specifically, we investigate how user generated gesture studies, in which potential users propose gestures that they feel best fit a given task (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Morris et al. [2014]), can be used to elicit highly learnable freehand gestures.

Mindfully Abstracting the Task from the Freehand Gesture

To support mindful abstraction, the literature suggests that the use of metaphor can support the learner in understanding the key principles, ideas or strategies of the taught material (e.g. Salomon and Perkins [1989]; Haskell [2001]).

To support learning, often across different systems, the use of metaphor in user interface design has a long history; from “piles” to organise documents (Mander et al. [1992]), a “house” metaphor to organise multimedia information (Vaananen [1993]), to the development of new user interfaces (Hofmeester and Wixon [2010]), widgets (Besacier et al. [2007]) and in situ guides for multi-touch interactive tabletops (Bragdon et al. [2010]).

Interface metaphors present to the user an abstraction of the system, often based on something familiar (e.g. a desktop), which invites the user to apply their understanding of this abstraction to perform different tasks (e.g. a trash-can might reasonably be used to remove documents the user no longer wants, but perhaps not permanently?). As Helander et al. [1997] suggests, the use of metaphor helps to structure the users’ mental model by supporting the link between the users’ interaction with a system and their prior knowledge of familiar concepts.

Building on this literature, we investigate how to use metaphor to support the mechanism of transfer of learning, mindful abstraction, for freehand gestures. Specifically, we investigate the introduction of metaphor during pre-use training to support mindful abstraction.

Travelling The Two Roads to Transfer of Learning Together

Finally, the literature highlights that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as “teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations” [Salomon and Perkins, 1989, p129].

Building on this work, in this thesis we,

1. Investigate how to support both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction), for new users of freehand gestures
   (a) To support learning to automaticity, we investigate how to draw on the prior knowledge and experience of potential end users to generate freehand gestures suitable for a range of tasks designed for interaction across different devices and applications
   (b) To support mindful abstraction, we investigate how metaphor, introduced during pre-use training, can support the user in abstracting the task from the freehand gesture such that a freehand gesture might be applied to analogous tasks across different devices and applications
2. Experimentally test the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning, by examining the effect on both
   (a) The ease of learning of freehand gestures for new users
   (b) The transfer of learning of freehand gestures by new users

1.2 Research Question

The question originally motivating this research was, *how can we support user interaction across different devices and applications?*

An initial investigation of the literature highlighted that interaction across devices and applications, for example, in ubiquitous computing environments, is a significant research challenge (Abowd and Mynatt [2000]; Rogers [2006]). A number of different solutions have been proposed to address this challenge for example, adaptive user interfaces (e.g., Gajos and Weld [2004]; Nichols and Myers [2006]) and speech interfaces (e.g., Kaila et al. [2009]; Xie et al. [2010]).

Similarly, freehand gestures are increasingly being used for interaction with a range of devices and applications (e.g. Mistry et al. [2009]; Fikkert et al. [2010]), with consumer products (e.g. Microsoft's Kinect and Samsung's Gesture Controlled TV) increasingly familiarising consumers with the use of freehand gestures for interaction with on-screen displays and avatars.

The literature suggests several advantages to freehand gestural interaction. The first is that freehand gestures remove the need for an intermediary input device allowing users to interact across devices and applications by "simple designation" [Baudel and Beaudouin-Lafon, 1993, p 28]. Secondly, freehand gestures can be highly expressive. For example, freehand gestures can be used to directly manipulate the position, orientation or size of an object on screen, specify commands such as *open* or *close* as well as issue commands which include parameters such as *open that document* or *close all documents* (Alpern and Minardo [2003]; Keskin et al. [2003]; Mistry et al. [2009]; Ren and O'Neill [2013b,a]). Finally, freehand gestures are used in everyday human communication and can provide an easily understood, naturalistic, method of user interaction (Wexelblat [1998]; Quek et al. [2002]).

Therefore, we refined our motivating question to, *how can we support the use of freehand gestural interaction across different devices and applications?*

Unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist is typically accomplished using a series of mouse clicks in a desktop environment, or taps on a touch-screen, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of potentially large sets of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform the analogous tasks on different, and potentially unknown, devices and applications.

To better understand this challenge we investigate the literature on transfer of learning (e.g. Thorndike [1906]; Judd [1939]; Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). Transfer of learning is the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p15]. For freehand gestural interaction, transfer of learning is the ability of users to perform previously learnt freehand gestures to interact with different devices and applications. This transfer of learning of freehand gestures is an important challenge and one which has received little attention in the literature.

Therefore, the research question addressed in this thesis is,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

Further investigation of the literature (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]) suggests two mechanisms which can support transfer of learning in new learners - 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. To support learning to automaticity the literature suggests that we should draw on the learners' prior knowledge and experience (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). To support mindful abstraction the literature suggests the use of metaphor (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]).

Furthermore, the literature highlights that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as "teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations" [Salomon and Perkins, 1989, p129].

Therefore, a number of research objectives are proposed in order to help answer our research question,

R01: How can we draw on the users' prior knowledge and experience to support learning to automaticity?

R02: How can we use metaphor to support mindful abstraction?

R03: How can we support both mechanisms of transfer of learning for new users of freehand gestures?

R04: Does supporting both mechanisms of transfer of learning make freehand gestures easier to learn for new users?

R05: Does supporting both mechanisms of transfer of learning make it easier for users to transfer learnt freehand gestures?

1.3 Research Methodology

This thesis investigates the transfer of learning of freehand gestures to support freehand gestural interaction across devices and applications. Moreover, this thesis investigates the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on both the learning and transfer of learning of freehand gestures.

To inform the work presented in this thesis we conducted an exhaustive *literature review* (Chapter 2) to develop an understanding of gestural interaction as well as transfer of learning. From this review of the literature two mechanisms (1. learning to automaticity and 2. mindful abstraction) are highlighted which, if supported, can facilitate transfer of learning.

To support learning to automaticity, a *generative empirical user study* is conducted (Chapter 3 Section 3.1). This study, informed by the literature review, draws on participant prior knowledge and experience to propose freehand gestures suitable for given tasks. The tasks presented to participants are developed through *scenario based design*. Both quantitative and qualitative data analysis is used to select freehand gestures for a proposed freehand gesture set.

Additionally, a *laboratory experiment* (Chapter 3 Section 3.2) is conducted to investigate the ease of learning of the freehand gestures selected from the generative empirical user study.

To support mindful abstraction, *brainstorming* (Chapter 4 Section 4.1) and *online questionnaires* (Chapter 5 Section 5.1) are used to develop the metaphors presented during pre-use training.

Furthermore, the review of the literature highlights that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as both learning and transfer of learning can be improved for new learners. A series of related *laboratory experiments* are conducted to test this observation (Chapter 4 and Chapter 5). Quantitative and qualitative data analysis is used to examine learning and transfer of learning from both a designers/experimenters perspective as well as from a user/participant perspective.

1.4 Research Contributions

This thesis presents a series of related studies, informed by a literature review, which

1. Investigates how to support both mechanisms (i.e. learning to automaticity and mindful abstraction) of transfer of learning for new users of freehand gestures
2. Experimentally tests the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning, by examining the effect on both the learning and transfer of learning of freehand gestures.

The results from these studies make a number of contributions. Addressing the former, this thesis contributes recommendations for designers on,

- Supporting learning to automaticity with user generated freehand gestures (RO1)
- Using metaphor to support mindful abstraction (RO2)
- How to support both mechanisms of transfer of learning through pre-use training for new users of freehand gestures (RO3)

Addressing the latter, this thesis contributes experimental evidence for, and recommendations for designers, on,

- Supporting the learning of freehand gestures for new users (RO4)
- Supporting the transfer of learning of freehand gestures for new users (RO5)

Further contributions resulting from the studies presented are recommendations for designers on,

- Predicting the ease of learning of freehand gestures for new users
- Evaluating the ease of learning of freehand gestures for new users
- Observations regarding the presence and absence of transfer of learning of freehand gestures
- Predicting the transfer of learning of freehand gestures for new users

1.5 Thesis Outline

In this section we present an overview of the thesis, highlighting the research objective(s) addressed in each chapter.

Chapter 2 sets the scene for the rest of this thesis by reviewing the literature on gestural interaction and transfer of learning. From this literature review, two mechanisms are highlighted which, if supported, can facilitate transfer of learning; 1. learning new material to automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. Building on this research this chapter explores how to support both of these mechanisms for new users of freehand gestures. Resulting from this literature review is the research question addressed in this thesis. Furthermore, we identify the research objectives addressed in the subsequent chapters of the thesis which help to answer our research question.

Chapter 3 focuses on supporting the user in learning freehand gestures to automaticity (RO1). This chapter presents two related studies which investigate how designers can draw on end user prior knowledge and experience to generate freehand gestures. The first study presented details a generative empirical study where end users propose freehand gestures for given tasks. The second study investigates the ease of learning of the freehand gesture set proposed as a results of the first study.

Chapter 4 focuses on supporting mindful abstraction (RO2) and examines the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures (RO4). This chapter explores how metaphor can be introduced during pre-use training to support mindful abstraction (RO3). Two types of metaphor are proposed; a *task metaphor* which explains the gesture in terms of an example task (e.g. as though you are widening a view) and a *performance metaphor* which describes the physical shape and movement of the gesture (e.g. looks like drawing the letter V). The study presented in this chapter examines the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures for new users. That is, we examine the effect of metaphor, introduced during pre-use training to support mindful abstraction, on the ease of learning of the freehand gesture set generated to support learning to automaticity proposed in Chapter 3.

Chapter 5 again examines supporting mindful abstraction (RO2) and examines the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures (RO5). This chapter further explores the introduction of metaphor during pre-use training to support mindful abstraction, examining how end users can generate suitable metaphors. The two related studies are presented in this chapter examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures for new users. That is, we examine the effect of metaphor, introduced during pre-use training to support mindful abstraction, on the transfer of learning to new tasks the freehand gestures generated to support learning to automaticity. The first study examines the transfer of learning of freehand gestures when participants are told to use the freehand gestures learnt during training to perform new tasks. The second study examines the transfer of learning of freehand gestures when participants are told they can use any freehand gesture they feel would best perform a new task and are not constrained to use those learnt during training.

Chapter 6 draws together the results of Chapters 3, 4 and 5 and presents the main contributions of this thesis. We critically examine the results of the studies presented to provide recommendations for designers on 1. how the support both mechanisms of transfer of learning for new users of freehand gestures, 2. supporting the learning of freehand gestures and 3. metrics to allow designers to predict and evaluate the ease of learning and transfer of learning of freehand gestures for new users. The primary contribution presented answers our research question providing recommendations for designers on supporting the transfer of learning of freehand gestures across different devices and applications.

Chapter 2

Literature Review

Freehand gestural interaction, that is gestures performed mid air without holding an input device or wearing markers for tracking, are increasingly being used as an interaction technique for a range of devices and applications. For example, Chen et al. [2003]; Fikkert et al. [2010]; Kray et al. [2010]; Mistry et al. [2009], explore how freehand gestural interaction can provide users with a rich, more naturalistic, method of interaction with devices and applications in different settings and contexts. Similarly, consumer products such as Microsoft's Kinect[1] and Samsung's Gesture Controlled TV[2] are increasingly familiarising consumers with the use of freehand gestures for interaction with on-screen displays and avatars.

Furthermore, the continued emergence of ubiquitous computing, has continued to drive research into interaction techniques, such as freehand gestures, suitable for interaction across different devices and applications. Ubiquitous computing[3] is a technological environment combining multiple fixed and mobile devices, as well as associated applications and services, that deliver to the user the means to pervasively support their everyday activities. Ubiquitous computing research explores the technological challenges of building and deploying multiple interconnected devices and applications in a range of contexts as well as, the tools and techniques that enable users to access and interact with the capabilities provided by such an environment.

Often, user interaction in ubiquitous computing environments is passive i.e. the environment adapts to the users' current activities requiring little or no direct user interaction. However, as Rogers [2006] argues, there is a need for a shift in focus from a "reactive view of people towards a more proactive one [whereby] instead of augmenting the environment to reduce the need for humans to think for themselves about what to do, what to select, etc., and

[1] Microsoft Kinect - `http://www.xbox.com/en-GB/xbox-one/accessories/kinect-for-xbox-one` (last accessed June 2015)

[2] Samsung Gesture Controlled TV - `http://www.samsung.com/uk/discover/in_the_home/at-ces-2013-with-samsung-electronics/` (last accessed June 2015)

[3] Term originally coined by Mark Weiser - see [Weiser, 1991]

doing it for them, we should consider how [ubiquitous computing] technologies can be designed to augment the human intellect" [Rogers, 2006, p 411]. That is, ubiquitous computing environments should actively engage with users, enabling them to interact with the different devices and applications in their environment.

Freehand gestural interaction is one interaction technique which could enable users to perform different tasks across different devices and applications. Freehand gestural interaction is a direct manipulation technique (Shneiderman [1983]; Hutchins et al. [1985]; Shneiderman [1998]) similar to mouse interactions on a graphical user interface or interactions with a computer game using a WiiMote[4]. Hutchins et al. [1985] suggests that systems which implement direct manipulation provide representations of the computational objects of interest. For example, icons, visualisations of data, widgets etc. but in ubiquitous computing environments these objects could also be physical devices. Similarly, direct manipulation provides physical actions which can be performed on computational objects of interest as well as rapid incremental and reversible operations where the effect is immediately visible.

Shneiderman [1983] highlights that the advantages of direct manipulation techniques are that, novice users can quickly learn basic functionality and expert users can work rapidly to carry out a wide range of tasks. Furthermore, intermittent users often retain operational concepts, so these users can often quickly re-learn or remember interactions with a system.

As a direct manipulation interaction technique, the literature suggests several advantages to freehand gestural interaction. The first is that freehand gestures remove the need for an intermediary input device allowing users to interact across devices and applications by "simple designation" [Baudel and Beaudouin-Lafon, 1993, p 28]. Secondly, freehand gestures can be highly expressive. For example, freehand gestures can be used to directly manipulate the position, orientation or size of an object on screen, specify commands such as *open* or *close* as well as issue commands which include parameters such as *open that document* or *close all documents* (Alpern and Minardo [2003]; Keskin et al. [2003]; Mistry et al. [2009]; Ren and O'Neill [2013b,a]). Finally, freehand gestures are used in everyday human communication and can provide an easily understood, naturalistic, method of user interaction (Wexelblat [1998]; Quek et al. [2002]).

However, unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. In traditional point-and-click desktop interfaces, and derivative touchscreen point-and-tap interfaces, the user has available a very small set of interface actions that are used to perform a range of different tasks. Gestural interface users, in contrast, are often provided with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in

[4]WiiMote - `https://www.nintendo.co.uk/Support/Wii/Usage/Wii-Remote/Basic-Operations/Basic-Operations-243993.html` (last accessed June 2015)

a playlist is typically accomplished using a series of mouse clicks in a desktop environment, or taps on a touchscreen, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of potentially large sets of freehand gestures. This is a particular challenge for gestural interfaces as, "opposed to buttons and menus, the user cannot guess which [gestures] are available and which [gesture] triggers which command" [Appert and Zhai, 2009, p 2294].

A further challenge for designers, and users, is that there is currently no standard set of freehand gestures for gestural interfaces. This may lead to different freehand gestures being used for the same tasks on different devices or applications. For example, to transfer data from one device to another, Yatani et al. [2005] propose a set of toss and swing gestures and Yoo et al. [2010] propose different cocktail mixing gestures. This is a significant limitation as users could be required to learn different freehand gestures for each device and application they use.

The development of a standard set of freehand gestures could reduce the burden on users to learn different freehand gestures for each device and application they use. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform analogous tasks on different, and potentially unknown, devices and applications. This transfer of learning of freehand gesturs is an important challenge and one which has received little attention in the literature.

This chapter sets the scene for the rest of this thesis by reviewing the literature on gestural interaction and transfer of learning. From this review we discuss how transfer of learning of freehand gestures can be supported for new users. In particular we focus on two mechanisms which the literature suggests can facilitate transfer of learning; 1. learning to automaticity and 2. mindful abstraction. Resulting from this discussion, we present the research question and research objectives addressed by the studies presented in this thesis.

2.1 Gestural Interaction

In this section we review the literature on the gestural interaction focusing on how researchers and designers typically design, or generate, gestures for interaction with different devices and applications.

Gestures can be created in at least two contrasting ways - designer generated and user generated. Designer generated gestures are often designed based on a principled design approach where factors such as hand fatigue and ease of performance are carefully considered. Designer generated gestures often make use of familiar physical or desktop interactions to generate novel gestural interactions. Furthermore, designer generated gestures are often designed to maximise ease of recognition by a given gesture capture and recognition technology.

In contrast, user generated gesture studies employ potential end users to propose gestures that they feel best fit a given task. Gestures are selected by finding consensus between potential end users as to which gesture is most suitable for the given task. Selected gestures often explicitly do not take into consideration the requirements of gesture capture and recognition technologies.

In this section we review the literature on both approaches to gesture generation, highlighting the advantages and challenges of each approach. Furthermore, we provide an overview of gesture in human communication and how researchers have used these communication gestures to inform the design of gestures for certain types of interaction with devices and applications. Finally, we highlight two important challenges to freehand gestural interaction across devices and applications - learnability and transferability.

2.1.1 Designer Generated Gestures

In response to the continued emergence of technology capable of recognising gestural interactions, new and novel gestures have been generated by designers. For example, Yatani et al. [2005] propose toss and swing gestures to send information between mobile devices. Choi et al. [2005] propose a set of gestures, drawn in the air with a cell phone, to control music applications and games. Scheible et al. [2008] propose a throwing gesture to transfer data from a cell phone to large public display. Yoo et al. [2010] proposes a set of gestures to transfer data between cell phones based on a cocktail mixing metaphor.

Similarly, Alpern and Minardo [2003] propose gestures for secondary task interaction whilst driving. Secondary tasks are tasks such as “go to favourite station” and “get directions to an intersection” which are performed by the driver whilst performing the primary task of driving. Alpern and Minardo propose gestures for *up, down, left, right* as well as numeric gestures which are used to interact with an interface projected on a heads up display.

Wu and Balakrishnan [2003] propose gestures for interaction with different interfaces and objects displayed on an interactive tabletop. Wu and Balakrishnan propose a number of gestures, exploring the use of one or two fingers as well as whole hand gestures, in a room planning application. The gestures proposed include, one and two finger selection, rotation and scaling as well as whole hand gestures for hiding and grouping objects.

Building on this research Wu et al. [2006] propose a set of design principles for generating gestures for interaction with direct touch surfaces such as interactive tabletops. Three design principles are proposed, 1. gesture registration, 2. gesture relaxation and 3. gesture reuse. Gesture registration is the beginning phase of every gesture and sets the context for subsequent interactions. Gesture relaxation refers to a two stage process where by the gesture is recognised by the system and then performed by the user. In the first stage the user performs the precise hand posture of a gesture until it is recognised by the system. In the second stage the user is able to relax this precise hand posture to more comfortably perform the interaction of the recognised gesture. Finally, gesture reuse refers to employing the same gesture, i.e., hand postures and finger touches, to perform analogous tasks across different contexts indicated during gesture registration. Wu et al. use these design principles to propose a set of gestures for interaction with publishing software designed for use on an interactive tabletop.

Mistry et al. [2009] take advantage of the improved capabilities of computer vision algorithms to recognise gestures performed mid air in front of the user. Mistry et al. define a set of freehand gestures based on familiar desktop interactions and familiar iconic gestures for interaction with mobile projected user interfaces.

Similarly, Ren et al. [2013] define freehand gestures which can be used to navigate visualisations on public displays. Billinghurst et al. [2013] define gestures for interaction in augmented reality on desktop computers and mobile devices. Steins et al. [2013] propose gestures which mimic the use of physical input devices (e.g. a steering wheel, joystick and mouse), to perform different tasks depending on the role being played in computer games (e.g. driving a car, flying a plane or selecting in game items). Bai et al. [2014] describe a prototype system where freehand gestures are defined, and combined with multi-touch gestures, to allow users to interact with wearable augmented reality devices such as Google Glass[5].

The primary advantage to designer generated gestures are that they are designed based on a principled design approach where factors such as hand fatigue and ease of performance are carefully considered. Furthermore, designer generated gestures often draw on familiar physical or desktop interactions to generate easily learnable gestures.

However, designers often place an emphasis on generating gestures which are easily recognisable by gesture recognition technologies. For example, Yatani et al. [2005]; Scheible et al. [2008] use accelerometer and gyroscope data provided by mobile devices to recognise gestures

[5]Google Glass - `http://www.google.com/glass` (last accessed June 2015)

performed by the user. The generated gestures are those which can be accurately and reliably recognised from this data with refinements to the design of a gesture primarily made when the performance by the user results in poor recognition.

A further challenge to designer generated gestures is the need to support ease of learning. To address this challenge designers often make use of familiar physical or desktop interactions. For example, Yoo et al. [2010] use cocktail mixing as a metaphor to design gestures to transfer data between cell phones, Wu and Balakrishnan [2003] draw upon observations of interactions made on physical desktops to inform the generation of gestures for interactive tabletops and Mistry et al. [2009] use gestures familiar in everyday communication (e.g. the *namaste* gesture) to generate gestures for interaction with mobile projected displays. However, a potential limitation to this approach is that generated gestures are personal to the designer with ease of learning reduced for those users who do not share the same (or similar) prior experiences.

2.1.2 User Generated Gestures

Designer generated gestures often place an emphasis on generating gestures which are easily recognisable by gesture recognition technologies. In contrast, researchers such as Baudel and Beaudouin-Lafon [1993]; Nielsen et al. [2004]; Wobbrock et al. [2009] investigate user requirements for gestural interaction. Baudel and Beaudouin-Lafon [1993] suggest that gestures be designed such that they not only incorporate established HCI design principles (e.g. feedback and reversible actions) but importantly undergo an iterative design process with real users.

Liu et al. [2006]; Epps et al. [2006]; Frisch et al. [2009] report user studies which seek to generate suitable gestures for interaction with interactive tabletops. Liu et al. [2006] examine how users interact with sheets of paper on real-world desktops from which they extracted gestures for reorienting objects on interactive tabletops. Similarly, Epps et al. [2006] conduct user studies to examine how users might wish to perform common interactions on an interactive tabletop. Frisch et al. [2009] examine how users interact with node-link diagrams on interactive tabletops by asking participants to perform different tasks using one hand, two hands as well as pen and hand together. From this study a set of gestures are proposed based on examination of the user generated gestures as well as think aloud data.

In gesture and speech interaction, researchers have investigated user generation of gesture and voice commands to better enable “natural and intuitive” interaction. For example, Robbe [1998] conduct a series of studies to determine which gesture and voice commands users naturally generate when asked to enact different interactions with different systems. The results suggest guidelines for designers on the generation of command languages which are composed of small, restricted voice commands from natural language, pointing gestures and combinations of both. Similarly, Voida et al. [2005] reports a study where voice and gesture commands are extracted from a Wizard-of-Oz study investigating user interaction in augmented reality environments.

Wobbrock et al. [2009], building on their previous work investigating user preferences for symbolic pen input (Wobbrock et al. [2005]), detail a user generated gesture study where potential end users generate gestures suitable for interaction with interactive tabletops. The guessability study presented by Wobbrock et al. [2009] presents participants with the starting position of an interface on an interactive tabletop followed by the end position of the interface. Participants are asked to generate the gesture(s) they would make in order to enact that task. From the results of this study Wobbrock et al. propose a set of gestures based on finding agreement, and resolving conflicts, between all participants as to the most suitable gesture for a given task.

Wobbrock et al. argue that user generated gesture studies result in the generation of gestures which are highly suited for the given task and can enable user to interact in a more naturalistic way. Using metrics such as agreement allows for the selection of gestures which are easily learnable for new users. Based on the results of a study examining the advantages of user generated gestures, Morris et al. [2010] report that users prefer gestures authored by large groups of people. Furthermore, Morris et al. report that gestures authored by large groups of people are more learnable because these gestures draw on the users prior knowledge and experience.

Similar studies have been undertaken to generate gestures to control the pan and zoom of a map interface on a large display (Fikkert et al. [2010]), for interaction across cell phones, large displays and interactive tabletops (Kray et al. [2010]), controlling infotainment systems in a car (Doring et al. [2011]) and for interaction with applications on a cell phone (Ruiz et al. [2011]).

Fikkert et al. [2010] describe a Wizard-of-Oz study in which users were asked to generate gestures to control the pan and zoom of a map interface on a large display out of reach of the user. As part of this investigation a different group of potential end user were asked to rate different proposed gestures for six different tasks used for interaction with a large display at a distance. Based on these studies they propose a set of gestures based on the agreement between users both in the generation study as well as the rating study.

Kray et al. [2010] describe a study where users were asked to generate gestures using a cell phone to interact with other cell phones, large displays and interactive tabletops. Doring et al. [2011] conduct a user generated gesture study to elicit gestures to be performed on the steering wheel of a car to control "infotainment systems". In both studies the authors propose a set of gestures based on agreement amongst participants.

Ruiz et al. [2011] report a user generated gesture study to generate gestures to invoke commands on a cell phone. Ruiz et al. adopt Wobbrock et al. [2009] agreement maximisation approach to select gestures. Similar to the results reported by Wobbrock et al., Ruiz et al. report high user preference for the gestures generated by potential end users.

Similarly, Lee et al. [2013] report a series of user generated gesture studies and Wizard-of-Oz studies to generate, refine and evaluate freehand gestures for user manipulation of digital content in the living room. Piumsomboon et al. [2013] report a user generated gesture study to better understand user preferences for interaction and manipulation of objects in augmented reality. Troiano et al. [2014] report a user generated gesture study to understand user preferences for interaction with elastic, deformable displays.

The primary advantage to user generate gesture studies are that they involve many users in the design of gestural interactions. These studies draw on the prior knowledge and experience of many users with gestures selected based on agreement between all the users that the gesture is the most suitable for a given task. The more suitable the gesture is often linked to ease of learning. For example, Wobbrock et al. [2005] compare user generated symbols to other designer generated symbols and report that user generated symbols are perceived as more suitable and report significant improvements in overall usability including ease of learning. Similarly, Nacenta et al. [2013] investigate the advantages of allowing users to "self define" suitable multi-touch gestures and report an improvement in memorability when compared to designer generated gestures.

However, one limitation to these studies is that the proposed gestures are often not implemented or tested in any real or prototype system. This makes it difficult to make real use comparisons of user preference and performance between user generated gestures and designer generated gestures. For example, although user preference data is gathered comparing gesture sets generated by designers and those selected from user generated gesture studies (e.g. Wobbrock et al. [2009]), because these studies cannot take into account factors such as system feedback, it is difficult to assess how user preference for user generated gestures might change with "real" use.

A further limitation is that for certain tasks, potential end users often propose a diverse range gestures. This is often for tasks which are quite novel or have no PC equivalent. For example, Wobbrock et al. [2009] report that there is little agreement between participants for the tasks *Accept* and *Reject* which are not familiar tasks performed when interacting with a PC. For even more abstract or novel interactions, for example "show me my location" or "send an email", it is likely that a diverse range of gestures will be proposed with little agreement between potential end users as to the most suitable gesture to perform these tasks.

Morris et al. [2014] identify this challenge (what Morris et al. call legacy bias) as a particular challenge of user generate gestures studies conducted to explore "emerging application domains, form factors, and sensing capabilities" [Morris et al., 2014, p 42]. For example, freehand gestural interaction across different devices and applications.

Morris et al. propose three extensions to user generated gesture studies - production, priming and partners. Production, requires potential end users to propose multiple different gestures for given tasks. Priming gets potential end users to think about the capabilities of a new form factor or sensing technology. Partners, gets potential end users to generate gestures in a group setting. These extensions provide guidance to designers on reducing legacy bias as well as increasing the novelty of gestures generated by potential end users.

2.1.3 Gestures in Human Communication

Another approach to gesture design is to draw on the gestures made as part of human communication. Gestures are a common part of human communication and are often used in conjunction with speech. Gestures range from pointing gestures to identify objects or indicate direction to communicating shapes, spatial relationships or abstract concepts.

Efron [1941]; McNeill [1992]; Kendon [1986] propose taxonomies of human gesture which categorise the gestures made as part of human communication. These taxonomies are summarised and compared by Wexelblat [1998].

Kinetographic (Efron), iconic (McNeill) and physiographic (Kendon) are gestures which picture the content of speech such as drawing the size of the box being described. Ideographic (Efron; Kendon) and metaphoric (McNeill) are gestures which portray the ideas of the speaker but not the content directly for example, moving the hand to indicate a gently flowing body of water when taking about a river. Batons (Efron), beats (or Butterworths) (McNeill) and gesticulation (Kendon) are gestures which mark the rhythm of the speakers speech. Symbolic (Efron; McNeill) and autonomous gestures (Kendon) are gestures which can be understood without speech, they are self contained and can often be culturally dependent for example, a wave goodbye or a halt gesture. Finally, deictic (McNeill) gestures are pointing gestures used to indicate objects or locations.

Similarly, Kendon [2004] distinguishes five categories of gesture - gesticulation, language-like gestures, pantomimes, emblems and sign language. These categories range in their formalism for example, gesticulation is "free form gesturing which typically accompany verbal discourse" and sign language contains a complete grammatical specification.

From these taxonomies of human gestures, the gestures most often utilised for gestural interaction with different technological systems are dietetic (pointing), symbolic or metaphoric gestures. This is often due to the limitations of gesture recognition technologies, similar to speech recognition, gestures such as gesticulations are difficult to interpret meaning from and sign language gestures are also limited in that the whole sentence needs to be correctly recognised if accurate interpretation of meaning is to be made.

However, all these categories of gestures can provide a rich foundation from which gestural interactions can be drawn. For example, Quek et al. [2002]; Wexelblat [1995] draw on these types of gestures when defining gestures to better enable natural and intuitive interaction. Wexelblat [1995] examines how gesticulation gestures can be used in virtual reality environments. Quek et al. [2002], explores how gestures which occur during speech can better enable speech and gesture interaction.

Similarly, Poggi [2002] examines how the different categorisations of gesture can support realistic interactions between humans and Artificial Intelligence agents. Sowa and Wachsmuth [2001] examine how iconic gestures can be used to identify objects in virtual reality environments. Rempel et al. [2014] explore how sign language gestures can be used in the design of gestures for human computer interaction.

2.1.4 Challenges of Freehand Gestural Interaction Across Different Devices and Applications

In this thesis we investigate how freehand gestures can be used for interaction across devices and applications. In this section we have presented a review of how current researchers and designers typically generate gestures for interaction with different devices and applications. Furthermore, we have presented how gestures from human communication might be used to enable rich gestural interactions.

One advantage to freehand gestures is that they can be highly expressive. For example, freehand gestures can be used to manipulate the position, orientation or size of an object on screen, issue commands such as *open* or *close* as well as issue commands which include parameters such as *open that document* or *close all documents* (Alpern and Minardo [2003]; Keskin et al. [2003]; Mistry et al. [2009]; Ren and O'Neill [2013b,a]).

Gestural interactions in current systems as well as those described in the literature, perform manipulations or issue single commands on a device or application. For example, the multi-touch gestures generated in Wobbrock et al. [2009] are to manipulate the size and location of objects on an interactive tabletop as well as to issue commands such as *copy* and *delete*. Similarly, Mistry et al. [2009] design freehand gestures to manipulate projected objects as well as issue commands such as *take a photograph* and *project the "home" menu*.

From these examples we can see that in current systems gestural interactions perform verb-like operations on the gestured at object (i.e. the object being manipulated or the device or application on which to perform a command). That is, similar to the subject-verb-object grammar rule in the English language, the gesture grammar implied in the examples above can also be described in the subject-verb-object form. For example, "I (the gesturing user) open (gesture verb) a document (gestured at object)" or "I (the gesturing user) rotate (gesture verb) the picture (gestured at object)".

Furthermore, building on the types of gestures accompanying speech in human communication, the manipulation gestures typically proposed for operations (or gesture verbs) such as *rotate* or *zoom in* closely resemble iconic gestures and for operations such as *select* or *move from A to B* they closely resemble deictic gestures. That is these typically proposed manipulation gestures depict movement, size or location information to the gestured at object. Whereas, the command gestures typically proposed for operations such as *copy* or *delete* closely resemble metaphoric gestures which depict the ideas of the speakers. Similarly, command gestures typically proposed for operations such as *project the "home" menu* closely resemble symbolic gestures which are self contained gestures that can be understood without speech and can often be culturally dependent.

Similar to the gestures designed or generated above, in this thesis we explore freehand gestures to perform manipulations or commands on different devices and applications. That is, freehand gestures for verbs such as *move, select, open* and *delete* which, allow users to perform a wide range of tasks but, as far as possible, are not specific to any one device or application.

Therefore, one of the challenges for designers, and users, is the need to support the learning of these potentially large sets of freehand gestures. Furthermore, the requirement of users to learn different freehand gestures for different tasks highlights the need for a common, consistent freehand gesture set for use across different devices and applications. In a similar way windows, icons and menus support users in learning new user interfaces, a common freehand gesture set could reduce the burden of learning freehand gestures for new devices and applications. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform the same or similar tasks on different, and potentially unknown, devices and applications.

Learnability of Freehand Gestures

Current approaches to support the learning of multi-touch gestures include dynamic guides and in situ learning through visual clues or instruction. For example, Bau and Mackay [2008] describe OctoPocus, a dynamic guide that combines on-screen feedforward and feedback to help users learn, execute and remember multi-touch gestures. They report that compared to Help menus, OctoPocus improves user learning of arbitrary gestures.

Similarly, Freeman et al. [2009] ShadowGuides provide on-demand assistance to the user by combining visualisations of the users' current hand posture and possible completion paths of the multi-touch gesture. Freeman et al. report that compared to video-based instruction, ShadowGuides has better support for learning with participants remembering more multi-touch gestures. Bragdon et al. [2009] report similar improvements in learning using GestureBar which discloses to the user how to perform multi-touch gestures through animated images, detail tips and an out-of-document practice area.

However, as Appert and Zhai [2009] and Kurtenbach et al. [1994] highlight, one important limitation to pen or multi-touch gestural interaction is that “gestures are not self-revealing”. This is also a significant challenge for freehand gestural interaction. Appert and Zhai suggest the use of visual clues to help users discover new gestures, while Kurtenbach et al. suggest the use of contextual menus that display available commands and how the user performs the gesture to invoke them.

For freehand gestural interaction, however, it is not always clear how these visual clues or contextual menus could be displayed to the user especially when interacting across multiple devices and applications (some of which may be non-visual) in a range of contexts. This suggests that for freehand gestural interaction across devices and applications, pre-use training is an important factor in supporting learnability.

Another, complementary, approach to supporting freehand gesture learnability is through the generation and design of freehand gestures. In presenting the work on the generation of gestural interactions, we can see the importance of supporting learnability by drawing on user prior knowledge and experience.

Gestural interaction designers often make use of familiar physical or desktop interactions to support ease of learning. Physical gestures such as throwing to transfer data from a cell phone to large public displays Scheible et al. [2008], cocktail mixing to transfer data between cell phones Yoo et al. [2010] or toss and swing gestures to send information between devices Yatani et al. [2005] draw on familiar experiences and invite the user to transfer these experiences to new contexts. Similarly, Mistry et al. [2009] define a set of gestures drawing on familiar desktop interactions and familiar iconic gestures for interaction with mobile projected user interfaces.

Furthermore, user generated gesture studies explicitly draw on the prior knowledge and experience of many potential end users to propose gestures suitable for a given task. Gestures are selected based on agreement amongst the participants that the gesture is the most appropriate for the given task. Wobbrock et al. [2009] use this approach to generate gestures for interactive tabletops where the proposed set of gestures are required to highly guessable and require little or no user training.

Similar studies have been reported where users generate suitable gestures for interaction with applications on a cell phone (Ruiz et al. [2011]), control the pan and zoom of a map interface on a large display (Fikkert et al. [2010]) and for interaction across cell phones, large displays and interactive tabletops (Kray et al. [2010]). Evaluations of selected gestures in these studies, as well as an evaluation by Morris et al. [2010], indicate that selecting gestures based on agreement between multiple potential users better supports gesture learnability because they draw on prior experience and familiar gestures from everyday life.

Transferability of Freehand Gestures

In the above section we discuss how to support the learning of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform analogous tasks on different, and potentially unknown, devices and applications.

To better understand this challenge, in the next section we investigate the literature on transfer of learning. Transfer of learning is the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p15]. For freehand gestural interaction, transfer of learning is the ability of users to perform previously learnt freehand gestures to interact with different devices and applications.

Investigating transfer of learning between text editors, Polson and Kieras [1985]; Polson et al. [1986, 1987] report a series of related studies which suggest that new users transfer previously acquired skills to perform new tasks and interactions. Similarly, Gustafson et al. [2011] investigate transfer of learning between physical and imaginary devices. Gustafson et al. report that users can transfer course spatial memory of icon locations from a mobile device (e.g. an iPhone) to the palm of the hand.

To support freehand gestural interaction across devices and applications, we argue that there is a need to better understand how to support the transfer of learning of freehand gestures.

2.2 Transfer of Learning

Transfer of learning is defined as the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p15] or "how previous learning influences current and future learning and how past or current learning is applied or adapted to similar or novel situations" [Haskell, 2001, p23].

Transfer of learning is different from learning. Learning "leads to a later performance we identify as more or less the same in a context we identify as more or less the same" [Salomon and Perkins, 1989, p115] whereas, transfer of learning is "when learning has a side effect we were not perfectly confident it would have" [Salomon and Perkins, 1989, p116].

In this section we present a review of the literature on transfer of learning. We first present an overview of the early, seminal work on transfer of learning. The seminal work by Thorndike [1924]; Judd [1939] and others, challenged established beliefs that education in certain disciplines (e.g., Latin) exercised and disciplined the mind producing overall better students with greater academic abilities. These early researchers began to articulate a definition of transfer of learning which would become a subject of much debate over the next 100 years.

Building on this overview, we present a review of modern studies examining transfer of learning. These studies provide mixed results, with researchers both reporting evidence of transfer of learning but equally failing to find evidence of transfer of learning. Despite these contradictory results, researchers generally agree that transfer of learning does take place. In reviewing these studies, we provide an overview of the complexities of studying transfer of learning as well as highlighting the discussions regarding the important variables thought to be involved in successful transfer of learning.

Next we present an overview of the critiques of transfer of learning as well as reviewing the reformulations of transfer of learning. These critiques and reformulations provide insight and reflections upon the traditional view of transfer of learning by exploring the different variables which might affect the transfer of learning from one situation to another.

Finally, we review the research which draws together the various perspectives of transfer of learning. This literature provides guidelines for researchers on the study of transfer of learning as well as the mechanisms thought to support transfer of learning. This research can be characterised as providing guidelines on 1. the when and where of transfer of learning i.e. under what circumstances is transfer of learning most likely to occur and be observed, and 2. the how of transfer of learning i.e. the mechanisms, techniques and strategies which can be adopted to promote and facilitate transfer of learning.

2.2.1 Early Investigations of Transfer of Learning

Early investigations into transfer of learning was a response the the doctrine of formal discipline prevalent among educators of the time. Seminal work by Thorndike [1924]; Judd [1939] and others, challenged established beliefs that education in certain "higher" disciplines (e.g. Latin and geometry) exercised and disciplined the mind producing overall better students with greater academic abilities.

The seminal work by Thorndike and Woodworth [1901a,b,c] reports a series of studies which investigate the effect of an "improvement in one mental function upon the efficiency of other functions". Where a mental function is defined as the "basis of such things as spelling, multiplication, delicacy in discriminating size, [...] chess playing, reasoning etc." [Thorndike and Woodworth, 1901a, pp 247].

In the first paper of this series, Thorndike and Woodworth [1901a] detail an experiment where participants were trained on area estimation of a set of rectangles. Participants would first estimate the area of a given rectangle and then check this estimation by reference area guide. Once a certain improvement had been observed in the ability of participants to correctly estimate the areas of a given set of rectangles, participants were asked to estimate the area of a different set rectangles and triangles without reference to the guide. Formal discipline would predict that the training in area estimation would result in participants performing similarly well in estimating the areas of a new set of rectangles as well as importantly, the new shapes. However, Thorndike and Woodworth found that the performance of participants in area estimation for this new set of rectangles and triangles was worse than that observed at the end of training. Similar results were found when examining participants ability to estimate magnitudes of length, area and weights (Thorndike and Woodworth [1901b]) as well as functions involving attention, observation and discrimination (Thorndike and Woodworth [1901c]).

Building on these results, Thorndike [1906] proposes the identical elements theory of transfer of learning. The identical elements theory of transfer of learning is when "one mental function or activity improves others in so far as, and because, they are in part identical with it, because it contains elements common to them" [Thorndike, 1906, p 243]. That is, Thorndike suggests that transfer of learning is dependent on "identical elements" between the taught skill or piece of knowledge and the transfer situation, where there are little or no similarities transfer of learning is not likely to occur if it occurs at all.

Thorndike [1924] reports similar results when investigating the broader proposition that the study of Latin improves academic performance in other subjects. Thorndike found no evidence that students who studied Latin performed better on standardised testing when compared to similar students studying other subjects such as book keeping. However, Thorndike does note that for certain subjects, such as French, there was evidence that study of Latin did have an effect on improved ability.

In contrast to Thorndike's identical elements theory of transfer of learning, Judd [1939] suggests that transfer of learning is dependent on the learner understanding the general principles or generalisations that form the basis of the subject. An experiment reported by Judd [1908] illustrates this general principles theory of transfer of learning. Judd trained participants to throw darts at targets underwater with one group instructed in the principle of refraction of light whilst a second group only practiced hitting the target. In the practice test participants in both groups did equally well in hitting a target 12 inches (30cm) underwater. However, when the target was moved to only 4 inches (10cm) underwater, the group instructed in the principle of light refraction performed considerably better than the control group. Judd argues that participants instructed in the principle of refraction of light transferred their understanding of this principle to the new situation.

Similarly, Robinson [1919] reports that the study of Latin itself does not improve a pupils ability in another discipline rather, it is the active study of Latin by the pupil and the methods of instruction, which plays the important role in the learners improved performance in other subjects. These results suggest that transfer of learning is the ability of the pupil to draw on their knowledge and experience, to reflect upon what they have learnt and then apply this knowledge, experience and understanding to a new situation.

Colvin [1923] suggests that transfer of learning can be both positive as well as negative. That is, the learning of a skill, fact, idea, principle etc. can either help the learner in another activity or have the effect of hindering learning another activity. However where transfer of learning is positive, Colvin identifies that it is most likely to occur when a "fact or skill secured in one kind of an activity [carries over] to another activity" as well as when "a principle, procedure, generalisation, or idea developed in one specific field is made to function in another" [Colvin, 1923, pp145].

Furthermore, Colvin suggests that "ideals are important in transfer". That is, the desire of the learner is important in successful transfer of learning and that different "attitudes" (positive and negative) correspondingly influence transfer of learning. Colvin suggests that "the subject in and of itself is not potent to secure the desired transfer [of learning], the pupil and the teacher are essential factors" [Colvin, 1923, pp145].

This view is supported by Gilliland [1923] who investigates the effect of the study of Latin on the ability to define English language words. The results of this study suggest that the study of Latin does not play a significant role in a pupils ability to define English words rather, it is the pupils desire, academic discipline and instruction (both length of time studying Latin as well as the method by which Latin is taught) that plays a more significant role. This observation is also reported by Otis [1922].

Overall these studies suggests that certain aspects of learning do transfer from one subject to another and from one situation to another. Thorndike [1906] proposes that transfer of learning is dependent on identical elements i.e. a specific fact or piece of knowledge which is applied to a similar situation. In contrast, Judd [1939] proposes that transfer of learning is dependent on the learner understanding the general principles or generalisations which are then applied to new situations. However, as Colvin [1923]; Gilliland [1923] suggest, various different variables, such as learner attitude and method of instruction, can also play a significant role is supporting transfer of learning.

Building on this early research, transfer of learning has been the subject of significant investigation and debate. These modern studies experimentally test Thorndike's identical elements theory of transfer of leaning as well as Judd's general principles theory of transfer of learning. Interestingly, these studies both find evidence of transfer of learning as well as fail to find evidence of transfer of learning. These contradictory results have lead to various discussions regarding the definition of transfer of learning as well as reformulations which highlight the important variables thought to positively influence and support transfer of learning. In the remainder of this section we provide and overview of these modern studies and reformulations of transfer of learning.

2.2.2 Modern Studies of Transfer of Learning

Following this early work, a number of researchers have undertaken studies examining transfer of learning. Interestingly, these studies both find evidence of transfer of learning and fail to find evidence of transfer of learning. In this section we provide and overview of these studies.

Studies which Find Evidence for Transfer of Learning

Gick and Holyoak [1980] conducted a number of studies investigating the identical elements theory of transfer of learning. Participants were first instructed on a problem and its solution. Participants were then presented with a new problem whose solution is analogous to the solution presented in the first problem. Gick and Holyoak found evidence for transfer of learning in that participants in the study were able to apply the solution described in the first problem to the transfer problem. However, Gick and Holyoak note that transfer of learning was more readily achieved when participants were given a hint that the first problem could help in solving the transfer problem.

Polson and Kieras [1985]; Polson et al. [1986, 1987] report a series of studies examining the transfer of learning between text editors. The results of these studies report that where there are similarities in a task structure and method of interaction between different text editors, users transfer skills acquired previously to perform analogous tasks or interactions. Similarly, Li and Chang [2011] report that where there are similarities between the user interfaces and functions provided by different systems, users are more likely to transfer learning between these different systems. However, Li and Chang also suggest that other variables, the delivery of training on the new system as well as individual factors such as motivation to learn, also play an important part in their observations of transfer of learning.

Investigating the general principles theory of transfer of learning, Clements and Gullo [1984] assessed the effects on children of learning computer programming on their (i) cognitive style (reflectivity, divergent thinking), (ii) metacognitive ability, (iii) cognitive development (operational competence, general cognitive measures), and (iv) ability to describe directions. The reported results found significant increases in ability for each measure when compared to a control group. These results suggest that participants in the study are able to transfer their learning of "higher order" skills to new situations. Similar results are reported by Lehrer et al. [1988] who investigate the effect of computer programming on acquisition of, for example, geometric concepts.

Similarly, Salomon et al. [1989a] report positive transfer of learning of self monitoring and self direction higher order skills from a study where students undertook training on a computer program designed to support students to be more strategic readers and writers. Brown [1989] report positive transfer of learning by preschool children of abstract concepts such as mimicry as a defence mechanism in animals in a series of studies examining transfer of learning through analogical reasoning. Campione et al. [1991] report positive transfer of learning of the self-monitoring and self-directing skills developed by "reciprocal teaching" (i.e. when the learners interact with each other under the guidance of a teacher), to other subjects studied by the participants, such as social studies and mathematics. Butterfield and Nelson [1991]; Halpern [1998] report similar results for the positive effect of teaching "higher order" skills on transfer of learning.

Studies which Fail to Find Evidence for Transfer of Learning

In contrast to studies which find evidence for transfer of learning, there are also a number of studies which fail to find evidence for transfer of learning. Pea and Kurland [1984] fail to find evidence for transfer of learning of "higher mental functions" which researchers such as Feurzeig et al. [1971] advocate are developed through learning computer programming.

Similarly, Reed et al. [1985] failed to find evidence for transfer of learning by college students in solving algebra problems despite prior instruction in the solutions to broadly similar problems. Mayer and Wittrock [1996] generally failed to find evidence for transfer of learning for various problem solving exercises. Reed et al. [1974]; Simon and Reed [1976]; Gick and Holyoak [1983]; Salomon and Perkins [1987] also generally fail to find, or find limited evidence for transfer of learning.

2.2.3 Critiques of Transfer of Learning

From the overview presented above, we can see that experimental evidence of transfer of learning is often mixed. Studies such as Clements and Gullo [1984]; Lehrer et al. [1988]; Brown [1989]; Salomon et al. [1989a]; Campione et al. [1991] find evidence for transfer of learning whereas as studies such as Gick and Holyoak [1983]; Pea and Kurland [1984]; Salomon and Perkins [1987]; Mayer and Wittrock [1996] find little evidence for transfer of learning.

These contradictory findings have resulted in a number of criticisms emerging regarding transfer of learning. For example, Detterman [1993] states that "transfer [of learning] has been one of the most actively studies phenomena in psychology [and that] reviewers are in total agreement that little transfer [of learning] occurs" [Detterman, 1993, p 5 and p 8]. Similarly, Schooler [1989] in summarising the experimental evidence for transfer of learning states, "the question for which we do have some empirical answers has to do with how generalizable cognitive training [(i.e. transfer of learning)] is from one subject area to another, as of now, the answer is not very much" [Schooler, 1989, p 11].

However, despite these criticisms, researchers generally agree that transfer of learning does occur (e.g. Bransford [2000]; Haskell [2001]; Royer et al. [2005]).

In addressing the criticisms of Schooler [1989]; Detterman [1993] and others, researchers highlight that transfer of learning is not adequately, or accurately, defined and as such difficult to predictably test or observe. For example, one definition of transfer of learning provided at the start of the chapter states that transfer of learning is "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p 15]. However, as Salomon and Perkins highlight, what constitutes different contexts is left to the researcher.

Similarly, the definition presented by Haskell [2001] that transfer of learning is "how past or current learning is applied or adapted to similar or novel situations", raises questions regarding 1. what knowledge do we expect to be applied or adapted (e.g. a fact, strategy, process etc.), 2. how much knowledge do we expect to be applied or adapted and 3. how do we judge the similarities of situations?

Addressing these concerns researchers have proposed a number of reformulations of transfer of learning. As Barnett and Ceci suggest these reformulations of transfer of learning address the "nature of transfer, the extent to which it occurs, and the nature of the underlying mechanisms" [Barnett and Ceci, 2002, p 612]. That is, these reformulations reexamine transfer of learning from different perspectives to enable researchers to better define transfer of learning and the mechanisms by which it occurs so that it can be better understood and experimentally tested.

2.2.4 Reformulations of Transfer of Learning

In this section we discuss the different reformulations of transfer of learning. This section is organised into three parts. The first part presents the types of transfer of learning proposed by researchers. These definitions often considerably overlap however, each definition characterises what is transferred (e.g. a specific piece of knowledge, skill, or principle) and when (e.g. to similar context or novel contexts). The second part presents the conditions under which transfer of learning is most likely to occur (e.g. between similar tasks or between similar environments where the learning takes place and transfer of learning is tested) as well as examining the primary variables which account for how transfer of learning occurs (e.g. identical elements, situated learning or metacognitive). The final part of this section presents the methods by which transfer of learning can be observed. This is, given that transfer of learning is often difficult to observe, and building on the different reformulations of how transfer of learning occurs, how can researchers experimentally test and observe transfer of learning. This also includes observations regarding how to predict transfer of learning and if predictions are even possible *a priory*.

Types of Transfer of Learning

The different types of transfer of learning described by researchers such as Gagne [1965]; Royer [1979]; Salomon and Perkins [1989] and others, characterise what is transferred (e.g. a specific piece of knowledge, skill, or principle) and when (e.g. to similar context or novel contexts). These definitions of the types of transfer of learning articulate either extreme of what many researchers consider to be a spectrum of transfer of leaning. That is, transfer of learning can be the application of a specific skill to a similar situation, the application of a specific skill to a slightly novel situation or the application of a general principle to a novel situation. The definitions of the types of transfer of learning define either extreme of this spectrum helping to provide a more detailed description and definition the what and when of transfer of learning.

Vertical and Lateral Transfer of Learning

Gagne [1965] identifies two types of transfer of learning - *vertical* and *lateral* transfer of learning. *Vertical transfer of learning* is where a skill or piece of knowledge learnt in one situation has a direct influence on the acquisition of a more complex skill or piece of knowledge learnt at a later point in time. Gagne suggested that the simpler skill is a necessary step to learning the more complex skill and as such, it is necessary to order training such that the hierarchical nature of the steps necessary to learn the more complex skill are taken into account.

Royer [1979] provide an example of the hierarchical nature of learning and transfer of learning suggested by *vertical* transfer of learning. Royer suggests that students who have learnt addition and multiplication will better acquire the skill of long division compare to students unfamiliar with the skills of addition and multiplication because both skills are required to perform the long division skill.

In contrast, *lateral* transfer of learning is “a kind of generalisation that spreads over a broad set of situations at roughly the same level of complexity” [Gagne, 1965, p 231]. As Royer et al. [2005], highlight *lateral* transfer of learning is less well defined than *vertical* transfer of learning. Royer et al. defines *lateral* transfer of learning as referring to “situations where [the learner] would learn things [such as] the correspondence between fractions and decimals, and the fact that letters can be the same even when their physical appearance changes” [Royer et al., 2005, p ix]. Royer suggests that an example of *lateral* transfer of learning is when a child recognises that fractions learnt in school can be used to decide how to divide a pie into equal portions.

Specific and Nonspecific Transfer of Learning

Royer et al. [2005] identifies *specific* and *nonspecific* transfer of learning. *Specific* transfer of learning “involves a situation where there is a clear similarity between the stimulus complex encountered in one situation and the stimulus complex encountered in another situation” [Royer et al., 2005, p ix].

To illustrate *specific* transfer of learning Royer et al. use Hoffding [1892] representation of the problem of recall. Hoffding suggested that recall could be conceptualised as follows - a learning event *A* is stored as an internal representation *a*, the response of the learned event is *b* which leads to the activation of the performance *B*. Together, this chain *A*-*a*-*b*-*B*, characterises recall when an event *A* again activates *a* which ultimately leads to the performance of *B*. Royer et al. suggest that *specific* transfer of learning can be characterised as when a similar event, e.g. *A'*, activates the internal representation of *A* which then triggers the previously learnt response resulting in the performance of *B*.

In contrast, Royer et al. state that *nonspecific* transfer of learning is where there is no "obvious relationship between the properties of two stimulus events, but the acquisition of one nonetheless influences the acquisition of the other" [Royer et al., 2005, p x]. Royer [1979] suggest that examples of *nonspecific* transfer of learning are "learning to learning" and "warm up" effects which are commonly reported as having a positive effect in studies investigating concept learning and list learning.

Detterman [1993] also identifies the distinction between *specific* and *nonspecific* transfer of learning. Detterman suggest that *specific* transfer of learning occurs when knowledge gained in one activity, e.g. memorising US State capitals, helps in the learning of similar studies such as geography. In contrast, *nonspecific* transfer of learning is where the content does not affect the learning of new material but rather the act of learning the original material helps in learning the new material. For example, in list learning studies where taught and practiced strategies, such as how to break up practice sessions and self motivation, help in list acquisition. Detterman highlight that *nonspecific* transfer of learning is often referred to a *general* transfer of learning as it is the general skills or practice which transfers.

Near and Far Transfer of Learning

Detterman [1993]; Royer et al. [2005] identify *near* and *far* transfer of learning. *Near* transfer of learning is where "there is a great deal of similarity between the conditions of original learning and the conditions in transfer learning" [Royer et al., 2005, p x]. Similarly, Detterman suggests that *near* transfer of learning is where learning is applied to situations which are "identical except for a few important differences" [Detterman, 1993, p 4]. The more similar the "original learning situation is to the new situation, the more likely it is to be called near transfer [of learning]" [Detterman, 1993, p 5].

In contrast, *far* transfer of learning is where there is "little similarity between two [learning] events" [Royer et al., 2005, p x] or "the more different the original and new situations, the more likely the transfer is called far transfer [of learning]" [Detterman, 1993, p 5].

Literal and Figural Transfer of Learning

Royer [1979] identifies *literal* and *figural* transfer of learning. *Literal* transfer of learning is the application of a complete piece of knowledge to a new situation. For example, using the skill of calculating an area of a rectangle to determine the size of carpet needed to fill a room of a house.

In contrast, *figural* transfer of learning is the use of a piece of knowledge to understand, or make sense, of a new piece of knowledge. Royer suggested that metaphor and simile are examples of *figural* transfer of learning where expressions such as "encyclopaedias are gold mines" and "our brain is like a computer" provide the learner with examples of prior knowledge and experience of another topic (e.g. the properties of gold mines and computers) to help understand the new topic.

Surface Structure and Deep Structure Transfer of Learning

Detterman [1993] identifies the distinction, primarily made by cognitive psychologists at the time, between *surface structure* and *deep structure* transfer of learning. The difference between the two is the similarities of the situation. For example, "all car dashboards give the same information but their dial configurations are different. Deep structure is the same but surface structure is different. On the other hand, an airplane dashboard contains dials similar to a car, but the information presented by those dials is different. For car and airplane dashboards, there is a similar surface structure but a different deep structure" [Detterman, 1993, p 5].

Low Road and High Road Transfer of Learning

Salomon and Perkins [1989] identify *low road* and *high road* transfer of learning. In contrast to the types of transfer of learning presented above which define what is transferred (e.g. a specific skill or concept) and when (e.g. to similar context or novel contexts), *low road* and *high road* transfer of learning indicate how transfer of learning is achieved by the learner.

Low road transfer of learning is achieved through learning a skill, piece of knowledge, etc., to automaticity. The mechanisms of *low road* transfer of learning are varied practice of the skill, piece of knowledge, etc. in a number of different contexts such that when the learner is presented with a similar stimulus the originally learnt skill, piece of knowledge, etc. is performed automatically by the learner.

In contrast, *high road* transfer of learning is achieved through the mindful abstraction of a skill, piece of knowledge, etc. The mechanisms of *high road* transfer of learning are the "deliberate, metacognitively guided and effortful, decontextualisation of a principle, main idea, strategy, or procedure, which then becomes a candidate for transfer" [Salomon and Perkins, 1989, p 126].

The definitions of the types of transfer of learning presented above attempt to characterise what is transferred (e.g. a specific piece of knowledge, skill, or principle) and when (e.g. to similar context or novel contexts). These definitions articulate either extreme of what many researchers consider to be a spectrum of transfer of leaning.

Often the definitions of these different types of transfer of learning considerably overlap. For example, *specific* and *near* transfer of learning describe a type of transfer of learning where the learner applies a piece of knowledge to a situation which is similar to that in which it was originally learnt. Similarly, *nonspecific* and *far* transfer of learning describe a type of transfer of learning where the learner applies a piece of knowledge to a situation which is novel or dissimilar to that in which it was originally learnt.

However, the differences between these types of transfer of learning highlight what learning is transferred and under what circumstances. For example, *near* and *far* transfer of learning primarily characterises transfer of learning between different tasks. Whereas, *specific* and *nonspecific* transfer of learning emphasises different levels of skill or knowledge acquisition by the learner and the resultant effect on transfer of learning.

Salomon and Perkins [1989] extend these types of transfer of learning and explicitly include how transfer of learning is achieved by the learner. *Low road* transfer of learning is *near* transfer of learning in that it is the application of a skill learnt in one situation to a similar situation. However, Salomon and Perkins highlight that *low road* transfer of learning is dependent on the learner learning this skill to automaticity. Similarly, *high road* transfer of learning is *far* transfer of learning in that it is the application of a skill learnt in one situation to a novel situation which, is dependent on the learner mindfully abstracting the main idea or principle of this skill. Importantly, Salomon and Perkins definition of *low road* and *high road* transfer of learning provide insight into how transfer of learning might be supported or fostered.

Reexamining How Transfer of Learning Occurs

In reformulating transfer of learning, various researchers have reexamined transfer of learning from reported experimental results to better understand the how of transfer of learning. In reexamining these experimental results, researchers have sought to better understand and explain, the conditions under which transfer of learning is most likely to occur (e.g. between similar tasks or between similar environments where learning takes place and transfer of learning is tested) as well as the primary variables which account for how transfer of learning occurs (e.g. identical elements, situated learning or metacognitive).

Royer [1979] suggests that these reformulations of the how of transfer of learning can be categorised into Environmental Theories and Cognitive Explanations. Similarly, Tuomi-Grohn and Engestrom [2003] suggest that transfer of learning theories can be categoried into three groups of reformulations; the first explains transfer of learning based on the transition of knowledge from one task to another, the second highlights the importance of the learner in transfer of learning and the third highlights the importance of the context in which the original knowledge is learnt in transfer of learning. Below we discuss the different reformulations of transfer of learning organised by the categorisation proposed by Tuomi-Grohn and Engestrom.

Task Perspective of Transfer of Learning

Thorndike [1906] proposed that transfer of learning is dependent on identical elements i.e. a specific fact or piece of knowledge which is applied to a similar situation. Singley and Anderson [1989], expand upon Thorndike's identical elements theory by examining how production systems which model human cognition, specifically the ACT* theory of skill acquisition (Anderson [1983]), can model and explain transfer of learning. A production system consists of condition-action rules (productions) and working memory. Productions are procedures which can be represented as IF-THEN statements. A production is executed when the conditions in the IF part of the production match the contents of working memory. ACT* extends this production system by adding a declarative memory to this model of human cognition which encodes facts in a special kind of long term memory.

Singley and Anderson argue that the ACT* theory can model transfer of learning in two ways. The first is that each production is equivalent to the identical elements proposed by Thorndike [1906] and therefore, transfer of learning can be explained by examining the number of productions common to two different tasks. Secondly, because the ACT* theory separates procedural and declarative knowledge, it is possible to define a broad explanation of transfer of learning based on the interactions between these two different types of knowledge. For example, declarative-to-procedural transfer of learning is when facts understood and interpreted into general procedures positively support the learning of a new production.

Similarly, schema representations of memory, such as those described by Reed [1993]; Dansereau [1995], detail how knowledge is represented and organised in memory. Schemas are general structures outlining a particular concept which are then instantiated for a given situation. Schemas are generated by learners through their previous experience with different exemplars of the general concept. Transfer of learning occurs when a new situation is recognised as resembling the patterns or qualities encoded by a previously acquired schema.

This is a broader view of the identical elements theory of transfer of learning and details how learning can be transferred to situations quite novel from that in which it was originally learnt. This broader view of the identical elements theory is further explored by researchers who suggest that transfer of learning occurs via analogy.

Analogical transfer of learning proposes that transfer of learning occurs when the transfer task is, and is recognised by the learner as, analogous to the originally learnt task. For example, Gick and Holyoak [1980] conduct a number of studies investigating transfer of learning by first instructing participants on a given problem and then presenting a new problem whose solution is analogous to that presented in the first problem.

In one such study, Gick and Holyoak [1980] instruct participants in a task that involved the presentation of the military problem and its solution[6]. Participants are then presented with an

[6] A general wishes to capture a fortress located in the centre of a country. There are many roads radiating

analogous problem, Dunker [1945]'s radiation problem[7], which they are asked to solve. Gick and Holyoak observed that participants were able to transfer the solution learnt for the original problem to the new problem.

From this series of studies, Gick and Holyoak noted that transfer of learning was more often observed when (i) the presentation of the problem during instruction was closely analogous to the solution sought for in the transfer problem and (ii) when participants recognised, or were provided with hints, that the training problem and the transfer problem had some relationship.

Similar results are reported by Brown et al. [1986]; Brown and Kane [1988]; Brown [1989]; Brown et al. [1989a] who examine analogical transfer of learning in young children. From these studies it is important to note that transfer of learning was more often observed when participants understood the principle behind the solution of the problem. That is, participants who gained an understanding of the deep structure of the problem and its solution more readily transferred this learning to the new problem when compared to participants who simply memorised the solution to the instruction problem.

Learner Perspective of Transfer of Learning

The observation that learner understanding is important to the success of transfer of learning is more in line with how Judd [1939] understood transfer of learning to occur. That is, Judd argues that transfer of learning is dependent on the learner understanding the material. Judd's theory of transfer of learning is that advocated and expanded upon by researchers who argue that to support transfer of learning we should teach for higher order skills such as critical thinking and meta cognitive awareness.

In reviewing the literature on transfer of learning, Barnett and Ceci [2002] suggest that an important field of research in transfer of learning is that which explores how to effectively teach critical thinking and metacognition which have been shown to promote transfer of learning. Teaching for intelligence and higher order skills include, meta cognitive awareness, critical thinking strategies, introspective awareness, self monitoring, thinking analytically, creatively or practically, self explanation strategies and self regulation strategies. This approach aims to foster awareness, deep thinking, active engagement, etc. in students such that the broader principles or strategies are learnt and can be applied to new situations. The emphasis, unlike task perspectives of transfer of learning, is on how to support the learner to transfer skills or

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outwards from the fortress. All have been mined so that while small groups of men can pass over the roads safely, a large force will detonate the mines. A full-scale direct attack it therefore impossible. The generals solution is to divide his army into small groups, send each group to the head of a different road, and have the groups converge simultaneously on the fortress. [Gick and Holyoak, 1980, p 309]

[7] Suppose you are a doctor faced with a patient who has an inoperable stomach tumour. You have at your disposal rays that can destroy human tissue when directed with sufficient intensity. How can you use these rays to destroy the tumour without destroying the surrounding healthy tissue? Dunker [1945]'s radiation problem as presented by Gick and Holyoak [1980]

knowledge rather than on understanding how a task is transferred to a new situation.

The metacognitive view of transfer of learning suggests that, "transfer [of learning] occurs when the problem solver is able to recognise the requirements of the new problem, select previously learnt specific and general skills that apply to the new problem" [Tuomi-Grohn and Engestrom, 2003, p 22]. Techniques such as metacognitive awareness (Bransford [2000]), teaching students from an analytical, creative or practical perspective (Sternberg [1988]) and critical thinking (Halpern [1998]) have been shown to support transfer of learning.

Similarly, constructivist approaches to transfer of learning (e.g. Kolb [1984]; Kolb et al. [2001]), are based on the active participation in problem-solving and critical thinking regarding a learning activity which students find relevant and engaging. Students construct their own knowledge by testing ideas and approaches based on their prior knowledge and experience. Students can then apply this experiential knowledge to new situations, and integrate the new knowledge gained with prior knowledge and experience.

Context Perspective of Transfer of Learning

In contrast to the above perspective on transfer of learning, researchers such as Lave and Wenger [1991]; Greeno et al. [1996] highlight the importance of the context in which the original knowledge is learnt on transfer of learning. This situated learning view of transfer of learning, suggests that learning is heavily influenced by the context in which it is learnt. Lave and Wenger; Greeno et al. suggest that transfer of learning occurs when the original learning is focused on learning by doing and on addressing real problems. This view is also advanced by researchers such as Ceci [1990]; Carraher and Schliemann [2002].

Similarly, sociogenetic perspectives on transfer of learning (e.g. Vygotskij [1986]; Varelas and Becker [1997]) highlight that learners are not only part of a physical world but also a cultural world. Learning is governed, constrained and mediated by this cultural world. Transfer of learning occurs when the learner redefines a learning context and the transfer context into a different level of meaning such the two contexts become equivalent. Vygotskij called this the law of equivalent concepts.

In mathematics education, transfer of learning has been examined under the context perspective of transfer of learning to examine why mathematics learnt in schools often fails to transfer outside the school. Situated cognitive perspectives on transfer of learning suggests that knowledge is learnt in one context for one purpose (Brown et al. [1989b]). For transfer of learning to occur learners must be engaged in discourse and other methods of meaning making such that bridges are made between the boundaries of these distinct pieces of knowledge (Dowling [1994]). Furthermore, researchers highlight the need to analyse the boundaries where bridges can be made to better understand transfer of learning (e.g. Muller and N. [1995]; Walkerdine [1997]).

Building on this research Evans [1999] proposes that knowledge can be defined as a set of practices arrived at through discourse. Evans suggests that there is a heavy influence of language and culture on the formation of these practices. Transfer of learning is the bridge between these practices and is often arrived at where practices overlap e.g. school and home mathematics.

The importance of boundaries and bridging between different knowledge to reformulate and better understand transfer of learning, is also advocated by Beach [2003]. Beach proposes a reformulation of transfer of learning called "consequential transitions" which explains how knowledge, learnt through continuous interaction with a given context and the transition of the leaner between contexts, can form generalisations which can be applied across contexts.

The reformulations of transfer of learning presented above reexamine transfer of learning from reported experimental results to better understand and explain, the conditions under which transfer of learning is most likely to occur as well as the variables which account for how transfer of learning occurs. Along with the descriptions of the different types of transfer of learning, these reformulations allow researchers to better define transfer of learning and the mechanisms by which it occurs such that transfer of learning can be better understood and experimentally tested.

Studying and Experimentally Testing Transfer of Learning

In Section 2.2.2 we discuss a number of modern studies which examine transfer of learning. The approach often taken in these studies involves researchers training learners in one task and testing for transfer of learning by examining improved performance in a transfer task. However, as the reformulations of transfer of learning presented above suggest, given the range of variables and conditions which potentially affect transfer of learning it is unsurprising that the results of these studies both find evidence for, as well as little evidence for, transfer of learning.

Drawing together various studies of transfer of learning, Barnett and Ceci [2002] propose a taxonomy of transfer of learning. This taxonomy not only allows researchers to evaluate and compare previously reported studies, but also supports researchers when designing studies examining transfer of learning by identifying "the dimensions against which transfer [of learning] of a learned skill may be assessed" [Barnett and Ceci, 2002, p 634].

Barnett and Ceci's taxonomy proposes a number of dimensions along which studies can be organised. These dimensions are divided into two overall factors - content (i.e., what is transferred) and context (i.e., when and where content is transferred from and to). Content is further divided into three dimensions - learned skill, performance change and memory demands. Learned skill is the specificity or generality of the skill which can be though of along the same lines as the types of transfer of learning described in Section 2.2.4 (e.g. *specific* and *nonspecific* or *near* and *far* transfer of learning). Performance change is a measure by which transfer of learning is expected to manifest, for example, an increase in the speed of performance or the accuracy of execution. Finally, memory demands is concerned with whether the learner is expected to reproduce a skill in a different setting or to select an appropriate approach.

Context is again further divided into six further dimensions - knowledge domain, physical context, temporal context, functional context, social context and modality. Knowledge domain refers to the different knowledge base (e.g. English, physics or maths) in which, or between which, transfer of learning is assessed. Physical context, is the environment in which the skill or piece of knowledge is learned and transfer of learning is assessed, for example, in or between the classrooms and the home. Temporal context, is the time elapsed between learning and transfer of learning being assessed. Functional context, is the setting in which the skill is learnt or the mind set evoked during learning, for example, academic learning or real world problems. Social context, refers to whether learning is undertaken as an individual or as part of a group. Finally, modality is the form in which transfer is assessed, for example, through examination of verbal discourse or through multiple choice exams.

In contrast, Lobato [2003] propose an alternative to this traditional approach of testing for transfer of learning. Lobato, suggest *actor-oriented transfer* as an alternative approach to studying transfer of learning which shifts the focus from the transfer of specific, sought for knowledge (such as indicated by increases in performance, what Lobato call the "experts view of transfer") to investigating the "the processes by which individuals generate their own similarities between problems" [Lobato, 2003, p 18]. That is, what are the processes by which the learner, drawing on their prior knowledge and experience, begins to understand, generalise and apply new knowledge to new situations.

The advantage to this approach is that it seeks to understand how the learner constructs a generalisation or strategy which then becomes a candidate for transfer of learning. This is particularly useful when examining transfer of learning as traditional experimental approaches seek to observe or measure a specific change in performance or application of knowledge often produce varied results.

These two approaches to the study of transfer of learning highlight the difficulty of experimentally observing transfer of learning. Barnett and Ceci's taxonomy highlights the myriad of variables which are often not easily controlled for in experimental settings. Lobato's actor-orientated approach acknowledges that observable or measurable transfer of learning of a specific skill or piece of knowledge is difficult to achieve, and focuses on examining the construction of understanding by the learner.

2.3 Supporting the Transfer of Learning of Freehand Gestures

Freehand gestures are increasingly being used for interaction with a range of devices and applications with consumer products increasingly familiarising consumers with the use of freehand gestures for interaction with on-screen displays and avatars.

Unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist is typically accomplished using a series of mouse clicks in a desktop environment, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of these potentially large sets of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform the same or similar tasks on different, and potentially unknown, devices and applications.

To support freehand gestural interaction across devices and applications, we argue that there is a need to better understand how to support the transfer of learning of freehand gestures. Therefore, the research question addressed in this thesis is,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

2.3.1 The Mechanisms of Transfer of Learning

In Section 2.2.4 we discuss the different reformulations of transfer of learning which elaborate the general definition of transfer of learning, seeking to better understand the "nature of transfer, the extent to which it occurs, and the nature of the underlying mechanisms" [Barnett and Ceci, 2002, p 612]. These reformulations suggest different types of transfer of learning which characterise what is transferred (e.g. a specific piece of knowledge, skill, or principle) and when (e.g. to similar context or novel contexts). Furthermore, these reformulations suggest different conditions under which transfer of learning is most likely to occur (e.g. between similar tasks or between similar environments where the learning takes place and transfer of learning is tested) as well as examining variables which account for how transfer of learning occurs (e.g. identical elements, situated learning or metacognition).

However, despite these reformulations providing more insight and understanding, researchers are still faced with challenges when studying transfer of learning. The primary reason is that the perception of similarity often differs between people and as such cannot be easily controlled for in experiments investigating transfer of learning. The reformulations of the types of transfer of learning provide more structure, or guidance, when evaluating similarity however, there is no rigid criterion by which this evaluation can be made and so remains subjective. Furthermore, it is still difficult to accurately predict what knowledge will transfer e.g. a subroutine, learning strategy, concept, etc. or any part or combination of these.

To address these challenges, Salomon and Perkins [1989] suggest that by understanding the how of transfer of learning i.e. the mechanisms that lead to transfer of learning, we can begin to explain how "previously learned elements (subroutines, principles, habits, etc.) can be (a) evoked and (b) successfully applied in a somewhat different situation" [Salomon and Perkins, 1989, p120].

Salomon and Perkins argue that there are two "roads" i.e. hows, to transfer of learning - low road and high road transfer of learning. Low road transfer of learning occurs when "a cognitive element is learned and practiced in a variety of contexts until it becomes automatic [which] on a later occasion, in another context, the stimulus characteristics sufficiently resemble those of the earlier [...] context to trigger automatically the element" [Salomon and Perkins, 1989, p120]. Again, this definition includes the problematic use of sameness or similarity which is difficult to accurately account for. However, the mechanism of low road transfer of learning is thorough, varied and diverse practice by the learner to automaticity.

Learning to automaticity is also suggested by Haskell [2001]; Bransford [2000] who argue that to support transfer of learning, learners should be provided with opportunities for extensive practice, with multiple examples in different contexts. The positive effect of learning to automaticity is also highlighted in the literature examining the identical elements theory of transfer of learning (e.g. Thorndike [1906]; Gick and Holyoak [1980]). That is, transfer of learning is dependent on the similarities between the taught skill and the transfer situation i.e. previous learning is triggered automatically due to the similarity between the transfer task and the learners previous learning.

Similarly, the positive effect of learning to automaticity is highlighted by Polson and Kieras [1985]; Polson et al. [1986, 1987] who report that users transfer previously acquired skills to perform tasks and interactions on new systems which share similar features to those previously learnt by the user. Gustafson et al. [2011] report that due to extensive use, users can transfer course spatial memory of icon locations between physical and imaginary devices, for example, from a mobile device (e.g. an iPhone) to the palm of the hand.

In contrast, high road transfer of learning involves the "mindful, deliberate processes that decontextualise the cognitive elements which are candidates for transfer" [Salomon and Perkins, 1989, p124]. The mechanism of high road transfer of learning is "mindful abstraction" i.e. the deliberate abstraction and understanding, by the learner, of "a principle, main idea, strategy or procedure, which then becomes a candidate for transfer" [Salomon and Perkins, 1989, p126].

Mindful abstraction is advocated by the general principles theory of transfer of learning (e.g. Judd [1939]; Butterfield and Nelson [1991]; Halpern [1998]). The reformulations of transfer of learning suggest different variables which can support mindful abstraction, for example, reciprocal learning (e.g. Campione et al. [1991]), teaching of metacognitive skills (e.g. Clements and Gullo [1984]; Lehrer et al. [1988]) or the use of metaphors and analogies (e.g. Haskell [2001]; Bransford [2000]) . Regardless of how it is achieved, by supporting mindful abstraction we support high road transfer of learning in the learner.

Building on this literature, in the remainder of this section we discuss how to support the mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) for new users of freehand gestures. Furthermore, resulting from this discussion we identify a number of research objectives to be addressed in the subsequent chapters of this thesis to help answer our research question.

2.3.2 Supporting Learning to Automaticity for Freehand Gestures

To support new users in learning freehand gestures to automaticity, the literature suggests that users are provided with opportunities for extensive practice, with multiple examples in different contexts (e.g. Salomon and Perkins [1989]; Haskell [2001]; Bransford [2000]).

Furthermore, Salomon and Perkins suggest that by drawing on the learners prior knowledge and experience the length of time taken to learn new material may be reduced. Similarly, Bransford [2000] highlights the role "personal, cultural and idiosyncratic experiences" play in supporting the learning of new material.

Research in human computer interaction also highlights the importance of drawing on the users' prior knowledge and experience to support the learnability of new systems. Norman [2002] states that designers should "use both knowledge in the world and knowledge in the head". Shneiderman [1998], states that designers should "strive for consistency". Consistency draws the users' prior knowledge and experience of similar systems to support the learning of a new system. Shneiderman suggests that designers should provide users with "consistent sequences of actions in similar situations; identical terminology in prompts, menus, and help screens; and consistent commands".

Consistency of user interaction across different systems has been shown to positively support learning. Polson and Kieras [1985] report that where new systems share large numbers of the same task structures and methods of interaction as other systems known to the user, the time to learn is reduced. Furthermore, Polson et al. [1986, 1987] report that consistency facilitates positive transfer of learning, that where there are similarities in a task structure and method of interaction, users transfer these previously acquired skills to perform new tasks and interactions.

For gestural interfaces, current approaches to support the learning of multi-touch gestures include dynamic guides and in situ learning through visual clues or instruction. For example, Bau and Mackay [2008] describe OctoPocus, a dynamic guide that combines on-screen feedforward and feedback to help users learn, execute and remember multi-touch gestures. Similarly,Freeman et al. [2009] ShadowGuides provide on-demand assistance to the user by combining visualisations of the users current hand posture and possible completion paths of the multi-touch gesture.

However, as Kurtenbach et al. [1994] and Appert and Zhai [2009] highlight, one important limitation to pen or multi-touch gestural interaction is that "gestures are not self-revealing". This is a significant challenge for freehand gestural interaction. Appert and Zhai suggest the use of visual clues to help users discover new gestures, while Kurtenbach et al. suggest the use of contextual menus that display available commands and how the user performs the gesture to invoke them. For freehand gestural interaction across devices and applications however, it is not always clear how these visual clues or contextual menus could be displayed to the user especially when interacting across multiple devices and applications. As such, we investigate how we can support the user in learning freehand gestures through pre-use training.

Therefore, to support learning to automaticity we investigate how we can draw on the prior knowledge and experience of end users to generate freehand gestures which are suitable for different interactions across devices and applications. We investigate how user generated gesture studies, in which potential users propose gestures that they feel best fit a given task (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Morris et al. [2014]), can be used to elicit highly learnable freehand gestures.

2.3.3 Supporting Mindful Abstraction for Freehand Gestures

The reformulations of transfer of learning suggest different variables which can support mindful abstraction for example, reciprocal learning or teaching of metacognitive skills. Salomon and Perkins [1989] highlight metaphor as a method by which high road transfer of learning can be evoked in the learner. Similarly, Haskell argues that transfer of learning "involves the use of figurative language with analogies and metaphors" [Haskell, 2001, p24].

Metaphor presents an abstraction to the learner of the material so as to convey the key principles, strategies, concepts, etc. which can then be applied to new situations. Metaphors, as Lakoff and Johnson argues, "play a central role in defining our everyday realities" and "govern our thought[s], not just [in] matters of the intellect, [but] also [in] our everyday functioning, down to the most mundane details, structur[ing] what we perceive, how we get around in the world, and how we relate to other people" [Lakoff and Johnson, 1980, p4].

In human computer interaction research, the use of metaphor in user interface design has a long history; from "piles" to organise documents (Mander et al. [1992]), a "house" metaphor to organise multimedia information (Vaananen [1993]), to the development of new user interfaces (Hofmeester and Wixon [2010]), widgets (Besacier et al. [2007]), in situ guides for multi-touch interactive tabletops (Bragdon et al. [2010]) and gestural interaction on mobile multi-touch devices (Hurtienne et al. [2010]). Furthermore, the pervasiveness of metaphor in everyday thinking and acting has been exploited by designers to elicit requirements, and identify problems, in user interface and interaction design (e.g. Frokjaer and Hornbaek [2008]; Antle et al. [2009])

Interface metaphors present to the user an abstraction of the system, often based on something familiar (e.g. a desktop), which invites the user to apply their understanding of this abstraction to perform different tasks (e.g. a trash-can might reasonably be used to remove documents the user no longer want, but perhaps not permanently). Helander et al. [1997] suggests metaphor structures the users' mental model by creating links between the users' system and task models, i.e. by supporting the link between the users' interaction with a system and their prior knowledge of familiar concepts.

Similarly, Gillan and Bias [1994] suggest that metaphor can change the users' cognitive structures by supporting the user to map procedural knowledge from one domain to another and altering the strength of the links between concepts in declarative memory. Procedural memory can be thought of as a set of production rules (IF-THEN statements) where a condition describes a state of the world that if met triggers an associated action. Declarative memory is a semantic network where nodes are concepts and the links between nodes are the relationships between these concepts. Gillan and Bias predict that learning is made easier where the metaphor provides a strong indication that the user can map known production rules to a new interaction or task.

The work by Gillan and Bias [1994]; Helander et al. [1997] and others, suggests that metaphor should convey to the user important abstractions. By supporting the user in gaining an understanding of the important abstractions learning is made easier.

However, Cooper [1995] claims that metaphor in user interface and interaction design is not only unhelpful, but harmful, arguing that metaphors can be applied too rigidly or provide the wrong model to users. Similarly, Erickson [1990] notes that a poor choice of metaphor results in significant differences between the users model of the system and the model of the system suggested by the metaphor. Such use of metaphors can "lead users astray or [...] lead them nowhere", resulting in poor usability and learnability.

Blackwell [2006] provides a review of metaphor in user interface design and highlights that early metaphorical user interface design often did not succeed because of an over reliance on metaphor. This over reliance often manifested in the use of metaphor for each user interface element, with different metaphors used to link together interactions across interface elements. These multiple metaphors often confused users with different or additional metaphors used to try to solve this confusion. In contrast, current use of metaphor, as Blackwell suggests, is more cautious, focusing on how abstraction can support usability and learnability.

Therefore, the choice of metaphor plays an important part in conveying key abstractions to the user and as such supporting mindful abstraction. Erickson [1990] suggests that to generate good user interface metaphors designers should (i) find the metaphors already present in the system, (ii) fully understand the systems functionality and (iii) understand what functions users may not understand. Similar guidelines on generating, evaluating and developing metaphors for user interface design are presented by Madsen [1994]; Saffer [2005].

Building on this literature, we investigate how the introduction of metaphor during pre-use training can support mindful abstraction. As suggested by Erickson [1990]; Madsen [1994]; Saffer [2005], the metaphors presented to users should "best support the areas [where] the users understanding is the weakest" [Erickson, 1990, p 73]. For freehand gestural interaction across devices and applications, we suggest user understanding is weakest and the introduction of metaphor during pre-use training should support the user in understanding either 1. the use of that freehand gesture when interacting with technology, other people or everyday life or 2. the physical features of a freehand gesture.

2.3.4 Supporting Both Mechanisms of Transfer of Learning for Freehand Gestures

Importantly, the two roads to transfer of learning are not mutually exclusive. The literature highlights that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as "teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations" [Salomon and Perkins, 1989, p129].

Furthermore, Salomon and Perkins [1989] discuss how failures to find evidence for transfer of learning can often be explained as a failure in one or both mechanisms. For example, Salomon and Perkins discuss the results presented by Scribner and Cole [1981] who examined the transfer of learning of cognitive abilities thought to result from literacy and schooling (e.g. decontextualisation, abstract thought and logical abilities) in the Vai people of Libya where, literacy is present but schooling is not. Salomon and Perkins suggest that the limited observed transfer of learning of these cognitive abilities can be accounted for by the limited use of literacy in the daily life of the Vai people i.e. the limited need to learn to automaticity the Vai written script. Where the transfer of learning of these cognitive abilities was observed, it was for a set tasks which specifically drew on examples of the use of Vai literacy practice. Transfer of learning beyond this narrow literacy practice was only observed in teachers of the Vai script as well as those with also understood the Arabic language.

Similarly, Salomon and Perkins discuss the failure to observe transfer of learning of higher order cognitive skills (e.g. rigorous thinking, mathematical abilities and thinking about thinking) thought to be supported through the skill acquisition of computer programming (e.g. Pea and Kurland [1984]; Kurland et al. [1986]; Salomon and Perkins [1987]). One possible explanation proposed is that learners do not gain sufficient mastery of programming skills to allow for transfer of learning. That is, the skills of programming are not learnt to automaticity to allow learners to apply this knowledge to new situations such as simple planning actives.

However, little or no transfer of learning of higher order cognitive skills was also observed in learners who had undertaken 2 years of programming instruction. Conversely, transfer of learning was observed in learners who were provided with high-level guidance from teachers as well as where part of learner instruction included debugging and debugging strategies. Salomon and Perkins suggest that the desired transfer of learning of higher order cognitive skills can not be achieved through learning to automaticity various programming skills. Rather mindful abstraction needs to occur in learners, and be supported by educators, to enable the transfer of learning of higher order cognitive skills as suggested from the results reported by, for example, Clements and Gullo [1984]; Klahr and Carver [1988].

Finally, Salomon and Perkins discuss the failure to observe transfer of learning in list learning experiments where the learning of one list is thought to positively impact the learning of a new list especially, if the new list contains one or more of the same list items as the original list (e.g. Asch [1969]). This failure to observe transfer of learning is also observed in the similar domain of problem solving where participants are taught a solution to a problem and asked to solve another problem for which the previously taught solution can be applied (e.g. Gick and Holyoak [1983]; Bransford et al. [1986]). Where transfer of learning does occur it is often reported when participants either recognise, or are prompted to recognise, repeated list items and so actively search for previously learnt list items or problem solutions. Similarly, transfer of learning is often reported when participants are taught the solution to a given problem in the context of other problem solving activities. Salomon and Perkins suggest that transfer of learning not only requires some level of automaticity of the learnt skill or piece of knowledge but, and perhaps more importantly, needs to be understood by the learner.

From these examples, although the failure to learn a skill to automaticity can have a negative impact on transfer of learning, it is more often the case that a failure in mindful abstraction contributes to the failure of transfer of learning. It is interesting to note that no examples are discussed regarding a negative impact of mindful abstraction on the learning to automaticity of a new skill or piece of knowledge. Similarly, the literature does not highlight any examples where the automatic transfer of learning supported by learning a new skill or piece of knowledge to automaticity is negatively influenced by mindful abstraction. That is, the act of reflecting on ones actions impeding or negatively impacting an automatic performance of a learnt skill to a new situation. Indeed Salomon and Perkins suggest that mindful abstraction whilst performing a skill learnt to automaticity should improve, rather than hinder, transfer of learning.

Where negative transfer of learning is discussed in the literature it is defined as when the learning of a skill or piece of knowledge has a detrimental effect on the acquisition of a new skill or piece of knowledge. One such example given in the literature (e.g Woltz et al. [2000]) is where a mariner who has previously learnt to respond to an alarm by pressing a red button, automatically performs the same action on a new system which is not appropriate. To address this negative transfer of learning, the literature suggests that mindfully attending to the learning of the new system should support the mariner to overcome the inappropriate automatic response.

Overall, the literature suggests that supporting the learning of a new skill or piece of knowledge to automaticity as well as supporting mindful abstraction of the key principle, idea, strategy etc. has a positive effect on transfer of learning.

Building on this literature we propose a number of research objectives to help answer our research question, ***how can we support the transfer of learning of freehand gestures across different devices and applications?***

R01: How can we draw on the users' prior knowledge and experience to support learning to automaticity?

R02: How can we use metaphor to support mindful abstraction?

R03: How can we support both mechanisms of transfer of learning for new users of freehand gestures?

R04: Does supporting both mechanisms of transfer of learning make freehand gestures easier to learn for new users?

R05: Does supporting both mechanisms of transfer of learning make it easier for users to transfer learnt freehand gestures?

Therefore, in this thesis we,

1. Investigate how to support both mechanisms of transfer of learning i.e. learning to automaticity and mindful abstraction, for new users of freehand gestures

    (a) To support learning to automaticity, we investigate how to draw on the prior knowledge and experience of potential end users to generate freehand gestures suitable for a range of tasks designed for interaction across different devices and applications (see Chapter 3)

(b) To support mindful abstraction, we investigate how metaphor, introduced during pre-use training, can support the user in abstracting the task from the freehand gesture such that a freehand gesture might be applied to analogous tasks across different devices and applications (see Chapter 4 and Chapter 5)

2. Experimentally test the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning, by examining the effect on both

   (a) The ease of learning of freehand gestures for new users (see Chapter 4)

   (b) The transfer of learning of freehand gestures by new users (see Chapter 5)

2.4 Chapter Summary

Freehand gestures are increasingly being used for interaction with a range of devices and applications (e.g. Mistry et al. [2009]; Fikkert et al. [2010]), with consumer products (e.g. Microsoft's Kinect and Samsung's Gesture Controlled TV) increasingly familiarising consumers with the use of freehand gestures for interaction with on-screen displays and avatars.

However, unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist is typically accomplished using a series of mouse clicks in a desktop environment, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of these potentially large sets of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform the same or similar tasks on different, and potentially unknown, devices and applications.

To better understand this challenge we investigated the literature on transfer of learning i.e. the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p15]. For freehand gestural interaction, transfer of learning is the ability of a user to perform previously learnt freehand gestures to interact across different devices and applications.

To support freehand gestural interaction across devices and applications, we argue that there is a need to better understand how to support the transfer of learning of freehand gestures. Therefore, the research question addressed in this thesis is,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

Further investigation of the literature (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]) suggests two mechanisms which can support transfer of learning in new learners - 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. To support learning to automaticity the literature suggests that we should draw on the learners prior knowledge and experience (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). To support mindful abstraction the literature suggests the use of metaphor (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]).

Furthermore, the literature highlights that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as "teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations" [Salomon and Perkins, 1989, p129].

Therefore, in this thesis we,

1. Investigate how to support both mechanisms of transfer of learning i.e. learning to automaticity and mindful abstraction, for new users of freehand gestures (RO3)
   (a) To support learning to automaticity, we investigate how to draw on the prior knowledge and experience of potential end users to generate freehand gestures suitable for a range of tasks designed for interaction across different devices and applications (RO1 - see Chapter 3)
   (b) To support mindful abstraction, we investigate how metaphor, introduced during pre-use training, can support the user in abstracting the task from the freehand gesture such that a freehand gesture might be applied to analogous tasks across different devices and applications (RO2 - see Chapter 4 and Chapter 5)
2. Experimentally test the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning, by examining the effect on both
   (a) The ease of learning of freehand gestures for new users (RO4 - see Chapter 4)
   (b) The transfer of learning of freehand gestures by new users (RO5 - see Chapter 5)

Chapter 3

Supporting Learning to Automaticity of Freehand Gestures

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). This chapter focuses on the former, that is, supporting the learning to automaticity of freehand gestures for new users.

As discussed in Section 2.3.2, Salomon and Perkins [1989] suggest that to support learning we should draw on the learners prior knowledge and experience. In doing so, they suggest, the length of time taken to learn new material can be reduced. Similarly, Bransford [2000], highlights that by engaging with the "personal, cultural and idiosyncratic experiences" of the learner we can support their learning of new material.

This chapter investigates how by drawing on the prior knowledge and experience of end users, we can support learning of freehand gestures. The first study reported extends the work on user generate gestures studies (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]) to the generation of freehand gestures for interaction across devices and application. The second study reported investigates if, as indicated in the literature (see Section 2.1.4), suitability does indeed indicate ease of learning of freehand gestures.

The remainder of this chapter is divided into two parts. First we present a user generated freehand gesture study where participants propose freehand gestures for given tasks. From this study we proposed a freehand gesture set which contains freehand gestures suitable to perform interactions or manipulations on a general set of devices or applications. The second part of this chapter reports a follow up study investigating the ease of learning of the freehand gesture set proposed in part one.

The studies presented in this chapter contribute to our research objectives by investigating how we can support the mechanism of transfer of learning - learning new material to automaticity. Specifically, the studies presented investigate,

R01: How can we draw on the users prior knowledge and experience to support learning to automaticity?

3.1 User Generated Freehand Gestures

In this section we present a user generated freehand gesture study where participants propose freehand gestures for given tasks. Tasks are extracted from a scenario exploring how future users might interact across devices and applications whilst travelling in a ubiquitous computing environment.

The study presented builds on work by Wobbrock et al. [2009], Fikkert et al. [2010], Kray et al. [2010] and others, to generate freehand gestures by drawing on the prior knowledge and experience of participants. Participants in the study propose suitable freehand gestures to perform different tasks. Freehand gestures are selected for inclusion in a freehand gesture set by maximising different metrics of suitability including the number of times a freehand gesture is proposed by participants, agreement (Wobbrock et al. [2009]) and guessability (Wobbrock et al. [2005]).

Furthermore, when analysing the proposed freehand gestures we maximise consensus across both interaction tasks and user tasks. That is, we maximise consensus between participants that the proposed freehand gestures are suitable for performing a generalised interaction (i.e. interaction tasks such as *Open, Stop, Show Me*) as well as for an instance of the use of the freehand gesture on an imagined device or application (i.e. user tasks such as *open a document, stop a video, show me my location*).

The remainder of this section is organised as follows. First we detail how the tasks used in the study were generated from a scenario developed with colleagues and industrial partners. Next we detail the freehand gesture generation study, the procedure followed, the data collected and how the data was analysed. Finally, we present the results of this analysis including the process followed to select suitable freehand gestures, design considerations and a categorisation of freehand gestures which we propose can predict the ease of learning of freehand gestures for new users.

3.1.1 Generating the Tasks Used in the Freehand Gesture Generation Study

Scenario

The scenario used to generate the tasks used in this study was developed through a collaboration between several academic and industrial organisations. This collaboration resulted in a set of related scenarios which explore the ways in which future users might interact with, and across, multiple different devices and applications in ubiquitous computing environments. The final scenario focused on the theme of *Augmented Travel* where multiple devices, applications, services and users come together to enable and enhance the traveling experience, from booking tickets to providing contextual information while en route. The full scenario can be found in Appendix A.1.1.

Interaction and User Tasks

As discussed in Section 2.1.4, we are particularly interested in exploring the generation of freehand gestures for the verbs (i.e. *Select*, *Move*, *Go To*) in the generated tasks. That is, the freehand gestures for commands or manipulations which allow users to perform a wide range of tasks but, as far as possible, are not specific to any one device or application.

Furthermore, we are interested in potential differences in the generation of freehand gestures when these verbs are accompanied by different objects, e.g. is the freehand gesture generated for *Open* the same when applied to a *Document* and an *Application*?

Therefore, the tasks presented to participants are a mix of *interaction tasks* and *user tasks*. An interaction task, as Foley et al. [1996] describe, is an "entry of a unit of information by the user" for example, entering text, issuing a command or specifying a position. We extend the basic interaction task categories proposed by Foley et al. for interaction with 2D user interfaces - position, text, select and quantify - to include gesture verbs such as *select, move, open, delete* and *show*.

In contrast a user task is the domain related task of the user e.g. *opening a document* or *zooming in to a map*. That is, the application of the interaction task (gesture verb) to a domain object (gestured at object). Where as domain object is defined by Beaudouin-Lafon [2000] as a "piece of application data that can be manipulated by the user". We extend this definition of domain object to also include devices which can be manipulated by the user when performing freehand gestural interactions.

Generating the Interaction and User Tasks

From the scenario in Appendix A.1.1, we abstracted example interaction tasks and user tasks for use in this study. Interaction tasks include familiar desktop interactions such as *Open,* *Delete and Move* as well as less familiar interactions such as *Show Me*. User tasks apply these different interaction tasks to different devices and applications from the scenario. For example,

- Open a [document/image/advert]
- Delete a [page in a document/image/advert]
- Show me the location of this cafe

Table 3.1 shows examples of the 52 interaction tasks and user tasks presented to participants in the study (for the complete list of tasks see Appendix A.1.2).

Table 3.1: Examples of the 52 Interaction and User Tasks Presented to Participants in the Freehand Gesture Generation Study.

Task No.	Task Type	Task
1	Interaction Task	Close
2	User Task	Close a document
3	User Task	Close an application
4	Interaction Task	Delete
5	User Task	Delete a piece of text
7	Interaction Task	Drop
8	User Task	Drop some media
16	Interaction Task	Move back
17	User Task	Move back in the video a few seconds
25	Interaction Task	Play
26	User Task	Play a video
27	Interaction Task	Search
28	User Task	Search a video
29	User Task	Search for a piece of text
35	Interaction Task	Show me
36	User Task	Show me information about this cafe
37	User Task	Show me my location
41	Interaction Task	Stop
42	User Task	Stop a video
43	Interaction Task	Turn off
44	User Task	Turn off a TV
47	Interaction Task	Zoom in
48	User Task	Zoom in to a image

3.1.2 Method

Design

A generative empirical study was conducted. Participants are asked to proposed freehand gestures to perform different tasks extracted from the scenario described in Section 3.1.1. Extracted tasks range from concrete tasks familiar to computer users e.g. *Select*, to more abstract tasks e.g. *Show me a*. Furthermore, tasks presented to participants are a mix of interaction tasks and user tasks. An interaction task is the action being performed by the user (e.g. *Open* or *Zoom In*). A user task is the domain related task of the user (e.g. *opening a document* or *zooming in to a map*).

Participants were asked to imagine themselves performing the tasks in the course of interacting with multiple different devices and applications in a ubiquitous computing environment. They were asked to visualise the interfaces and objects they might be interacting with. No props or interfaces were provided in order to focus the participants on generating freehand gestures that would allow them to perform the task, rather than focusing on the freehand gestures that could be made to interact with a specific interface or object.

Participants

Twenty-two participants took part in the study, aged from 20 to 44 with a mean age of 29. 16 participants were male and 6 were female. All participants were right-handed. All participants were recruited from around the University of Bath. No reward was given for their participation.

Procedure

Participants were run individually. Each participant was provided with the context in which they should imagine themselves performing the freehand gestures. The experimenter read aloud each task in turn and the participant made a freehand gesture of their own choice to perform the task. The order of the tasks was randomised for each participant. The freehand gestures performed by each participant were video recorded for later analysis. All of the material used in this study can be found in Appendix A.1.3.

Analysis

The goal of this study is to generate and select freehand gestures suitable to perform interactions or manipulations on a general set of devices and applications. To achieve this we decided to analyse the resulting data focusing on selecting suitable freehand gestures for the verbs in the tasks, e.g. *Select*, *Move*, *Go To*.

Wobbrock et al. detail a procedure where proposed gestures are selected for inclusion in a gesture set based on maximising calculated metrics of either guessability (Wobbrock et al. [2005]) or agreement (Wobbrock et al. [2009]) . To select a gesture for each task, Wobbrock et al. [2005] first selected the gesture with the highest guessability score (or agreement score in Wobbrock et al. [2009]). Where a task has the same highest scoring gesture as another task, the task where that gesture has the higher guessability score is chosen and the next highest scoring gesture is selected for the other task.

We adopt this procedure to select freehand gestures. We calculate both agreement and guessability, presented along with the number of proposed freehand gestures for each task, to examine the suitability of proposed freehand gestures for each task. To calculate agreement we use Equation 3.1 as defined by Wobbrock et al. [2009]. Where, r is a given task in the set of all tasks R, P_r is the set of proposed gestures for the task r, and P_i is a subset of identical gestures from P_r.

Wobbrock et al. define agreement as the consensus between participants that the most proposed gesture is suitable for the given task. Agreement scores range from 0 to 1 with 0 indicating no agreement between participants that the gesture is suitable for the task (i.e. all participants propose different gestures to enact the given task) and 1 indicating perfect agreement that the gesture is suitable for the task (i.e. all participants propose the same gesture to enact the given task). The advantage to this metric is that the variation in the number of different gestures proposed for a given task is reflected in the agreement score. For example, comparing the agreement scores calculated in 3.2 and 3.3 shows that, although both *move* and *adjust* have the same number of participants proposing the most popular gesture, 3.2 has a higher agreement score than 3.3 due to the lower variation in the number of other gestures proposed to enact this task.

Furthermore, Wobbrock et al. observe that higher agreement scores are reflected in higher ratings by participants when asked if the gesture is a “good match for its intended purpose”.

$$A = \frac{\sum_{r \in R} \sum_{p_i \subseteq P_r} \left(\frac{|P_i|}{|P_r|} \right)^2}{|R|} \tag{3.1}$$

$$A_{move} = \left(\frac{10}{20}\right)^2 + \left(\frac{5}{20}\right)^2 + \left(\frac{5}{20}\right)^2 = 0.375 \tag{3.2}$$

$$A_{adjust} = \left(\frac{10}{20}\right)^2 + \left(\frac{3}{20}\right)^2 + \left(\frac{3}{20}\right)^2 + \left(\frac{2}{20}\right)^2 + \left(\frac{2}{20}\right)^2 = 0.315 \tag{3.3}$$

To calculate guessability we use Equation 3.4 as defined by Wobbrock et al. [2005]. Where P is the set of proposed gestures for the all tasks, and P_s is the proposed gesture for task s, which is a member of the resultant symbol set S. Wobbrock et al. define guessability as how likely a new user would guess the correct gesture in the absence of any training. Wobbrock et al. use guessability as an indication as to the suitability of a gesture in a "walk-up-and-use" setting. Similarly, we use guessability as a broad indication of suitability and potential ease of learning of a freehand gesture. We present guessability along with the number of proposed freehand gestures for each task, to examine the suitability of proposed freehand gestures for each task.

$$G = \frac{\sum\limits_{s \in S} |P_s|}{|P|} .100\% \tag{3.4}$$

Additionally, we maximise the suitability of a freehand gesture across both interaction and user tasks. That is, we examine if the freehand gestures generated by participants are the same when these verbs are accompanied by different nouns. For example, is the freehand gesture generated for *Open* the same when applied to a *Document* and an *Application*? By maximising suitability across both interaction tasks and user tasks we maximise consensus between users that the proposed freehand gestures is suitable for performing the generalised interaction (e.g. *Open*, *Stop*, *Show Me*) as well as for an instance of this freehand gestures use on an imagined device or application (e.g. *open a document*, *stop a video*, *show me my location*).

3.1.3 Results

The resulting video record was analysed to investigate the freehand gestures generated by participants. Two researchers independently analysed the resulting video and produced descriptions of the freehand gestures made by participants. To ensure that the resulting analysis of freehand gestures was based on the same observed freehand gesture an inter-rater reliability test was conducted. Each researcher gave a description of the freehand gesture made for each task. These descriptions were then compared and a Kappa statistic was produced to determine consistency between the researchers. The results of the test indicate a very high level of agreement between the descriptions of the freehand gestures performed by each participant (Kappa = 0.818, $p<0.001$).

The results of the study are presented as follows. First we examine the freehand gestures generated by participants for interaction tasks and present an emerging grouping of freehand gestures based on observed differences in the calculated metrics of suitability. Next we examine the proposed freehand gestures generated for user tasks. Finally, we compare the proposed freehand gestures for both interaction and user tasks.

Freehand Gestures Proposed for Interaction Tasks

Table 3.2 shows the proposed freehand gestures for each interaction task. In total 93 freehand gestures were proposed for all interaction tasks, of these proposed freehand gestures 47 are unique. The number of freehand gestures proposed for each interaction task ranged from 3 to 8 with the median number of proposed freehand gestures being 5 (Q_1=4, Q_3=6, IQR=2).

Table 3.2 shows the agreement and guessability scores calculated for each of these proposed freehand gestures. Agreement scores provide an indication as to the consensus between participants that the most proposed freehand gesture is suitable for the given task (see Section 3.1.2). Guessability scores, provide an indication as to how easily guessable a freehand gesture is in the absence of any training (see Section 3.1.2).

The median agreement score for the freehand gestures proposed by participants for all interaction tasks is 0.313 (Q_1=0.248, Q_3=0.583, IQR=0.335). The median guessability scores for the most proposed, unique, freehand gestures for all interaction tasks is 41% (Q_1=30%, Q_3=69%, IQR39%).

Inspecting Table 3.2 shows that for the interaction tasks *Stop, Pick Up, Open, Select, Close* and *Drop* participants, by majority, propose one freehand gesture. For example, the *Stop* interaction task has 3 proposed freehand gestures with one freehand gesture proposed by 20 of the 22 participants. Similarly, the *Drop* interaction task has 4 proposed freehand gestures with one freehand gesture proposed by 14 of the 22 participants.

This consensus between participants that the most proposed freehand gesture is best suited for the interaction task is reflected in the agreement scores which range from 0.483 to 0.831. Similarly, for the most proposed freehand gestures, guessability scores range from 64% to 91%.

The remaining interaction tasks (*Go Back, Zoom In, Zoom Out, Move Forward and Move Back, Play, Go To, Delete, Search, Turn On, Turn Off and Show Me*) have agreement scores ranging from 0.178 and 0.339 with participants often not proposing one freehand gesture clearly more than any other. For the most proposed freehand gestures, guessability scores range from 14% to 50%.

However, for the interaction tasks *Go Back, Zoom In, Zoom Out, Move Forward and Move Back*, the difference between the proposed freehand gestures is often a related to the direction or orientation of the movement of the hands. For example, the most proposed freehand gestures for the *Zoom Out* interaction task include (i) a movement together, (ii) a movement apart, (iii) a movement backward and apart and (iv) a movement forwards and apart.

In contrast participants propose a range of freehand gestures for the interaction tasks *Play, Go To, Delete, Search, Turn On, Turn Off* and *Show Me*. For example, for the interaction task *Play*, participants by majority propose a point gesture but also propose gestures such as mimicking a movie camera, opening a book and rolling their fingers in a circle.

Table 3.2: Interaction Tasks, Proposed Freehand Gestures, Guessability and Agreement Scores from the Freehand Gesture Generation Study.

Interaction Task	**Gesture Made**	**Proposed By**	**Guessa - bility**	**Agree - ment**
Stop	halt, show palms of hands	20	91%	0.831
	X shape	1	5%	
	movement right	1	5%	
Pick Up	picking up or grabbing an object	18	82%	0.690
	movement upwards	3	14%	
	point	1	5%	
Open	open book or movement from hands together outwards	17	77%	0.620
	point or double point	3	14%	
	movement upwards	1	5%	
	movement backwards	1	5%	
Select	pointing or double point, one or two hands	17	77%	0.616
	grabbing	2	9%	
	enclose the object	2	9%	
	halt	1	5%	
Close	close book or movement from hands apart then together	16	73%	0.583
	draw an X shape	5	23%	
	movement downwards	1	5%	
Drop	dropping or letting go of an object	14	64%	0.483
	movement downwards	6	27%	
	draw X shape	1	5%	
	point	1	5%	
Go To	point or double point, point with both hands	10	45%	0.343
	indicate start and move to end	7	32%	
	physical movement	4	18%	
	raise hand	1	5%	
Go Back	movement left	11	50%	0.339
	movement backwards	5	23%	
	point behind	3	14%	
	movement right	3	14%	

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Table 3.2 – *Continued from previous page*

Interaction Task	Gesture Made	Proposed By	Guessa - bility	Agree - ment
Delete	draw an X	9	41%	0.318
	throwing away	8	36%	
	movement left (off screen?)	2	9%	
	closing	1	5%	
	point	2	9%	
Zoom In	movement outward or apart	11	50%	0.308
	movement forwards and together	4	18%	
	movement together or inwards	3	14%	
	movement forwards and apart	1	5%	
	pinching	1	5%	
	bringing object closer to self	1	5%	
Move Back	movement backwards	9	41%	0.298
	movement left	7	32%	
	physically move back	3	14%	
	movement right	2	9%	
	movement downwards	1	5%	
Play	point, double point etc.	11	50%	0.293
	movie camera or play button (mimic of video features)	3	14%	
	movement left	2	9%	
	open movement	2	9%	
	movement right	1	5%	
	rolling fingers	1	5%	
	movement forwards	1	5%	
	wave	1	5%	
Search	circle motion with tail	9	41%	0.252
	question mark	4	18%	
	sifting or searching through something	4	18%	
	magnifying glass	2	9%	
	eyes	2	9%	
	shrug	1	5%	
Zoom Out	movement together or inwards	7	32%	0.248
	movement apart	7	32%	
	movement backward and apart	4	18%	
	movement forwards and apart	1	5%	

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Table 3.2 – *Continued from previous page*

Interaction Task	**Gesture Made**	**Proposed By**	**Guessa - bility**	**Agree - ment**
	movement backwards	2	9%	
	point behind	1	5%	
Show Me	point	5	23%	0.248
	indicate at self or show self	5	23%	
	open book or make a frame to view	8	36%	
	show someone else - movement forwards	2	9%	
	circle movement	1	5%	
	movie camera	1	5%	
Turn On	pointing or double point, one or two hands	8	36%	0.231
	rotate hand (right)	5	23%	
	open hands	4	18%	
	movement up	2	9%	
	movement down	1	5%	
	grab	1	5%	
	halt	1	5%	
Move Forward	movement forwards	6	27%	0.202
	physically move forward	5	23%	
	movement left	5	23%	
	movement right	3	14%	
	movement backwards	1	5%	
	movement upwards	1	5%	
	wind wheel clockwise	1	5%	
Turn Off	closing something (book, hands or eyes)	6	27%	0.178
	draw an X	5	23%	
	rotate hand (right)	3	14%	
	rotate hand (left)	3	14%	
	pointing or double point, one or two hands	2	9%	
	slit throat	1	5%	
	swipe away	1	5%	
	opening something (book, hands, eyes)	1	5%	

Emerging Groups of Interaction Tasks

Emerging from this examination of the proposed freehand gestures are three groups of interaction tasks. These different groups, discussed below, group together interaction tasks based on differences in the suitability of the proposed freehand gestures when considering our three metrics of suitability.

Furthermore, drawing on the literature on gesture in human communication (see Sections 2.1.3 and 2.1.4), we discuss the differences in the types of proposed freehand gestures in these groups to further distinguish between the groups. In particular we focus on the continuum of gestures proposed by Kendon [2004]. Kendon's continuum details the different levels of formalism of gestures from those which are highly structured and conventionalised to those which are largely improvised. We suggest that these different levels of formalism account for the prior knowledge and experience which can be drawn on by the user as well as broadly reflect different levels of ease of learning. That is, gestures which are highly structured and conventionalised are easier to learn than those gestures which are largely improvised.

Group 1

Group 1 contains interaction tasks where the majority of participants propose one freehand gesture with only a few participants proposing alternatives.

From the results of this study, Group 1 contains the interaction tasks *Close, Drop, Open, Pick Up, Select* and *Stop*. The number of proposed freehand gestures in this group range from 3 to 4 with a median of 3.5 (Q_1=3, Q_3=4, IQR=1). The agreement scores in this group range from 0.483 to 0.831 and the guessability scores for this group range from 64% to 91%.

Examining the types freehand gestures proposed by participants we suggest that they can be classified as either symbolic gestures (i.e. gestures which can be understood without speech, are self contained and can often be culturally dependent for example, a wave goodbye or a halt gesture) or deictic gestures (i.e. pointing gestures). On the continuum of gestures proposed by Kendon [2004] these would be emblem gestures which are quotable gestures and often replace speech.

For example, the most proposed freehand gestures for the task *Close* are 1. *closing a book* with 16 out of 22 participants proposing this freehand gesture and 2. *drawing a X shape* with 5 participants proposing this freehand gesture. Both of these proposed freehand gestures could be classified as symbolic gestures as they could be understood outside of the context of the task being performed. For example, "I (gesture user) make a closing book gesture to close (gesture verb) a document (gestured at object)" or "I (gesture user) draw an X shape to close (gesture verb) a document (gestured at object)". Both of these proposed freehand gestures seem to draw on the participants prior experience of actions performed either in the real world (i.e. with physical books) or from desktop computer interaction (i.e. the "X" button to close open windows on the users' desktop).

Similarly, the most proposed freehand gesture for the task *Stop* is a *halt* gesture with 20 out of 22 participants proposing this freehand gesture. Again, this could be classified as a symbolic gesture and could be understood outside the context of the task e.g. "I (gesture user) make a halt gesture to stop (gesture verb) the video (gesture object)".

Group 2

Group 2 contains interaction tasks where participants propose a range of freehand gestures which typically differ in the direction or orientation of the hands however, broadly the proposed freehand gestures are similar.

For example, for the *Zoom Out* interaction task the most proposed freehand gestures are (i) a movement together, (ii) a movement apart, (iii) a movement backward and apart and (iv) a movement forwards and apart. From these proposed freehand gestures we can see that most participants agree that to perform the interaction task *Zoom Out* both hands should "move apart". However, participants are unsure whether this should be performed flat, moving forwards or moving backwards from the imagined device or application.

From the results of this study, Group 2 contains the interaction tasks *Go Back, Move Back, Move Forward, Zoom In* and *Zoom Out*. The number of proposed freehand gestures in this group range from 4 to 7 with a median of 6 (Q_1=4.5, Q_3=6.5, IQR=2). The agreement scores for this group range from 0.202 to 0.339 and the guessability scores for this group range from 27% to 50%.

Examining the types freehand gestures proposed by participants we suggest that they can be classified as iconic gestures (i.e. gestures which picture the content of speech such as drawing the size of a box being described). On the continuum of gestures proposed by Kendon [2004] these would be mime gestures which are gestures which act on a given object.

For example, the two most proposed freehand gestures for the task *Move Back* are 1. *movement backwards* with 9 out of 22 participants proposing this freehand gesture and 2. *movement left* with 7 participants proposing this freehand gesture. Both of these freehand gestures could be classified as iconic gestures as they perform a manipulation on the imagined device or application. For example, "I (gesture user) make a movement backwards to move back (gesture verb) in a collection of images (gesture object)" or "I (gesture user) make a movement left to move back (gesture verb) in a collection of images (gesture object)".

Similarly, the two most proposed freehand gestures for the task *Zoom Out* are 1. *movement together or inwards* with 7 out of 22 participants proposing this freehand gesture and 2. *movement apart* with 7 participants proposing this freehand gesture. Again, these proposed freehand gestures could be classified as iconic gestures. For example, "I (gesture user) make a movement together and inwards to zoom in (gesture verb) on a map (gesture object)" or "I (gesture user) make a movement apart to zoom in (gesture verb) on a map (gesture object)".

From these examples it is also important to note that the spatial cognition of the user is an important consideration. Spatial cognition relates to how a user conceptualises spatial and temporal movements in relation to the body. This is often culturally specific. For example, for some users temporal movements such as a movement backwards in time, might be conceptualised as movement of the hand from right to left. However, for some participants a movement backwards in time might be conceptualised as a movement of the hand towards the body.

Similarly, the spatial frame of reference of the user in relation to the task being performed is another important consideration. That is, how the user conceptualises their interaction with an object. For example, for the task *Zoom In* is the user indicating that they want to drill down (i.e. with a movement inwards) into a map or are they indicating that they want to map to stretch (i.e. with a movement apart) to zoom into?

Group 3

Group 3 contains interaction tasks where participants propose a wide range of different freehand gestures. However, unlike Group 2 there are no common features across the proposed freehand gestures. Furthermore, the most proposed freehand gestures in this group often contain the most proposed freehand gestures for interaction tasks in Group 1.

For example, the most proposed freehand gesture for *Play* is a "pointing" freehand gesture similar to the most proposed freehand gesture for *Select*. Similarly, the most proposed freehand gesture for *Turn Off* is a "closing a book" freehand gesture similar to the most proposed freehand gesture for *Close*.

From the results of this study, Group 3 contains the interaction tasks *Delete, Go To, Play, Search, Show Me, Turn On* and *Turn Off*. Similar to Group 2, the number of proposed freehand gestures in this group range from 4 to 8 with a median of 6 (Q_1=5, Q_3=8, IQR=3). The agreement scores for this group range from 0.178 to 0.343 and the guessability scores for this group range from 23% to 50%.

Examining the types freehand gestures proposed by participants we suggest that they can be classified as metaphoric gestures (i.e. gestures which portray the ideas of the speaker but not the content directly for example, moving the hand to indicate a gently flowing body of water when taking about a river). On the continuum of gestures proposed by Kendon [2004] these would be gesticulation gestures which are free form gesturing which typically accompany verbal discourse.

For example, the proposed freehand gestures for the task *Search* include 1. *drawing a circle motion with tail* with 9 out of 22 participants proposing this freehand gesture, 2. *drawing a question mark* with 4 participants proposing this freehand gesture and 3. *sifting or searching* *through something* with 4 participants proposing this freehand gesture. These freehand gestures could be classified as metaphoric gestures as they indicate a task to be performed but unlike Group 1 are not as easily understood outside of the context of the task or Group 2 which perform a manipulation on a device or application. That is, "I (gesture user) draw a circle motion with tail (perhaps a "Q[estion]") to search (gesture verb) for an image on a device (gesture object)" or "I (gesture user) make a sifting gesture to search (gesture verb) for an image on a device or application (gesture object)".

Similarly, the proposed freehand gestures for the task *Show Me* include 1. *indicate at self* with 5 out of 22 participants proposing this freehand gesture and 2. *make a frame* with 8 participants proposing this freehand gesture. Again, these proposed freehand gestures could be classified as metaphoric gestures. That is, "I (gesture user) indicate at (my)self to show me (gesture verb) my location on a device or application (gesture object)" or "I (gesture user) make a frame to show me (gesture verb) my location on a device (gesture object)".

Differences Between Groups

To further test these differences between groups we conducted a Kruskal-Wallis test (non-parametric ANOVA) for the number of proposed freehand gestures, agreement scores and guessability scores for each of the groups detailed above.

Examining the number of proposed freehand gestures in each of the proposed groups, a Kruskal-Wallis test reports that there was a statistically significant difference between the groups ($H(2)=9.88$, $p=0.007$), with a mean rank of 4 for Group 1, 11.2 for Group 2 and 13 for Group 3.

Examining the agreement scores in each of the proposed groups, a Kruskal-Wallis test reports that there is a statistically significant difference between the groups ($H(2)=11.42$, $p=0.003$), with a mean rank of 15.5 for Group 1, 6.9 for Group 2 and 6.2 for Group 3.

Finally, examining the guessability scores in each of the proposed groups, a Kruskal-Wallis test reports that there is a statistically significant difference between the groups ($H(2)=11.48$, $p=0.0032$), with a mean rank of 15.5 for Group 1, 7.1 for Group 2 and 6.1 for Group 3.

These results suggest that the most proposed freehand gestures for the interaction task in the different groups differ in their suitability (as measured by the number of proposed freehand gestures, agreement and guessability). The results of the Kruskal-Wallis tests indicate that Group 1 contains freehand gestures more suitable for the corresponding interaction tasks than Group 2, which in turn contains freehand gestures more suitable for the corresponding interaction tasks than those in Group 3.

Additionally, examining the proposed freehand gestures by participants in Group 1 they can be categorised as symbolic and deictic gestures, Group 2 as iconic gestures and Group 3 as metaphoric gestures. Based on the continuum of gestures proposed by Kendon [2004], Group 1 are emblem gestures, Group 2 mine gestures and Group 3 gesticulations. This latter observation suggests that the freehand gestures proposed by participants range in their formalism and this difference in formalism is reflected in the groups of freehand gestures. That is, the proposed freehand gestures in Group 1 are gestures which have a high level of formalism, they are quotable gestures and often replace speech in human communication, Group 2 are gestures which perform manipulations with a device or application they are semi-formal in that they are likely to be similar between participants but perhaps differ depending on the spatial cognition or assumed spatial frame of the participant and Group 3 are gesticulation gestures which are largely improvised gestures in human communication and convey ideas rather than conventions (emblems) or manipulations (mimes).

Comparing the Proposed Freehand Gestures for Interaction Tasks and User Tasks:

In the previous section we have presented the results examining the proposed freehand gestures for interaction tasks. However, are the freehand gestures proposed for interaction tasks also proposed for corresponding user tasks? For example, are freehand gestures proposed by participants for the interaction task *Open*, also proposed by participants for the user tasks *open a document* and *open an application*? In this section we examine the proposed freehand gestures for the user tasks presented to participants and compare these proposed freehand gestures to those proposed for the corresponding interaction tasks.

Table 3.3, shows six example user tasks - two from each of the emerging groups of interaction tasks. Table 3.3 shows the proposed freehand gestures for the interaction task as well as the proposed freehand gestures for the corresponding user tasks. Also shown are, the number of participants who proposed the freehand gesture, agreement and guessability scores.

From Table 3.3 we can see that the different levels of freehand gesture suitability, described by the emerging groups of interaction tasks proposed above, are also evident in the freehand gestures proposed for the corresponding user tasks.

Group 1

Group 1 contains interaction tasks where the majority of participants propose one freehand gesture with only a few participants proposing alternatives. Furthermore, the freehand gestures proposed by participants can be classified as either symbolic or deictic gestures which on the continuum of gestures proposed by Kendon [2004] are emblem gestures.

This is also observed in the freehand gestures proposed for the corresponding user tasks. For example, 12 of the 22 participants propose the “open a book” freehand gesture for the user task *open an application* with few alternatives being proposed. The alternative freehand gestures proposed for the *open an application* user task are, a “pointing” freehand gesture (8 participants), a “swipe sideways” freehand gesture (1 participant) and a “move apart” freehand gesture (1 participant).

Similarly, for the user task *open a document* 18 of the 22 participants propose the “open a book” freehand gesture. For user task *stop a video*, 15 of the 22 participants propose the “halt!” freehand gesture which is the most proposed freehand gesture for the interaction task *Stop*.

Furthermore, as with the freehand gestures proposed for the corresponding interaction tasks, the proposed freehand gestures for these user tasks are also symbolic or deictic gestures. Based on the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are emblem gestures which have a high level of formalism, they are quotable gestures and often replace speech in human communication.

Group 2

Group 2 contains interaction tasks where participants propose a range of freehand gestures which typically differ in the direction or orientation of the hands however, broadly the proposed freehand gestures are similar. Furthermore, the freehand gestures proposed by participants can be classified as iconic gestures which on the continuum of gestures proposed by Kendon [2004] are mime gestures.

Again this can be observed in the freehand gestures proposed by participants for the corresponding user tasks. For example, for the user tasks *zoom out of an image* and *zoom out of a map*, participants propose freehand gestures which typically differ in either a movement “apart” or “inwards”. This, again, is consistent with that observed for the interaction task *Zoom Out* where participants are split between (i) a movement together, (ii) a movement apart, (iii) a movement backward and apart and (iv) a movement forwards and apart as the most suitable freehand gesture.

Similarly, for the user tasks *zoom in on an image* and *zoom in on a map*, participants are split between the direction “apart” and “inwards” as to the most suitable direction of movement of the freehand gesture.

Furthermore, as with the freehand gestures proposed for the corresponding interaction tasks, the proposed freehand gestures for these user tasks are iconic gestures. Based on the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are mime gestures which perform manipulations on a device or application. Mime gestures are semi-formal in that they are likely to be similar between participants but perhaps differ depending on the spatial cognition or assumed spatial frame of the participant.

Group 3

Finally, Group 3 contains interaction tasks where participants propose a wide range of different freehand gestures. However, unlike Group 2 there are no common features across the proposed freehand gestures. Additionally, the most proposed freehand gestures in this group often contain the most proposed freehand gestures for interaction tasks in Group 1. Furthermore, the freehand gestures proposed by participants can be classified as metaphoric gestures which on the continuum of gestures proposed by Kendon [2004] are gesticulation gestures.

This is also observed in the freehand gestures proposed by participants for the corresponding user tasks. For example, for the user task *delete an image* participants propose 5 freehand gestures which include a "close a book" freehand gesture. The two most proposed freehand gestures are "throw away" and "draw an X". Both of these gestures have similar number of participants who propose them, agreement scores and guessability scores.

Similarly, for the user task *delete a piece of text*, participants propose 4 freehand gestures however, for this user task there is more consensus between participants with participants split between a "throw" (10 participants) and a "draw an X" (8 participants) freehand gesture. For the user task *turn on a TV* participants propose 6 freehand gestures which include a "point" and "open a book" freehand gesture.

Furthermore, as with the freehand gestures proposed for the corresponding interaction tasks, the proposed freehand gestures for these user tasks are metaphoric gestures. Based on the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are gesticulation gestures which are largely improvised gestures in human communication and convey ideas rather than conventions (emblems) or manipulations (mimes).

Table 3.3: Comparing Proposed Freehand Gestures for Both Interaction Tasks and User Tasks

Task	**Gesture Made**	**Proposed By**	**Guessa - bility**	**Agree - ment**
Open	open book or movement from hands together outwards	17	77%	0.620
	point or double point	3	14%	
	movement upwards	1	5%	
	movement backwards	1	5%	
Open an Application	open book (and point)	12	55%	0.434
	point, double point etc.	8	36%	
	one hand swipe sideways	1	5%	
	fingers together, move apart (facing upwards)	1	5%	
Open a Document	open book (and point)	18	82%	0.690
	point, double point etc.	3	14%	
	hands low, move up	1	5%	
Stop	halt, show palms of hands	20	91%	0.831
	X shape	1	5%	
	movement right	1	5%	
Stop a Video	halt sign (inc. point)	15	68%	0.521
	point	5	23%	
	move hand right	1	5%	
	put fist forward, circular motion	1	5%	
Zoom Out	movement together or inwards	7	32%	0.248
	movement apart	7	32%	
	movement backward and apart	4	18%	
	movement forwards and apart	1	5%	
Zoom Out of an Image	movement backwards and apart	7	32%	0.236
	movement apart or outwards (and point)	6	27%	
	movement inwards or together (and point)	5	23%	
Zoom Out of a Map	movement apart or outwards (and point)	8	36%	0.202

Continued on next page

Table 3.3 – *Continued from previous page*

Task	Gesture Made	Proposed By	Guessa - bility	Agree - ment
	hands together, move apart and backwards	4	18%	
	movement inwards or together (and point)	3	14%	
	movement backward or towards self	2	9%	
	hands apart, move together and forwards	1	5%	
Zoom In	movement outward or apart	11	50%	0.308
	movement forwards and together	4	18%	
	movement together or inwards	3	14%	
	movement forwards and apart	1	5%	
	pinching	1	5%	
	bringing object closer to self	1	5%	
Zoom In to an Image	movement inwards or together (and point)	10	45%	0.380
	movement apart or outwards (and point)	9	41%	
	movement forwards	1	5%	
	twist hands and move forwards (like camera zoom?)	1	5%	
	point at self, move hand towards self	1	5%	
Zoom In to a Map	movement apart or outwards (and point)	8	36%	0.262
	movement inwards or together (and point)	7	32%	
	movement forwards (and together)	3	14%	
	referent(?) and movement inwards or together	2	9%	
	point at self, move hand towards self	1	5%	
Delete	draw X shape	9	41%	0.318
	throwing away	8	36%	
	movement left (off screen?)	2	9%	
	point	2	9%	
	closing	1	5%	
Delete an Image	throw away (inc. point)	8	36%	0.260
	draw and X	7	32%	
	close like gesture (inc. point)	2	9%	

Continued on next page

Table 3.3 – *Continued from previous page*

Task	Gesture Made	Proposed By	Guessa - bility	Agree - ment
	push to side	2	9%	
	draw and X and throw away	2	9%	
Delete a Piece of Text	throw to side	7	32%	0.198
	draw and X	4	18%	
	draw an X with text referent	4	18%	
	throw to floor	3	14%	
Turn On	pointing or double point, one or two hands	8	36%	0.231
	rotate hand (right)	5	23%	
	open hands	4	18%	
	movement up	2	9%	
	movement down	1	5%	
	grab	1	5%	
	halt	1	5%	
Turn On a TV	point, double point etc.	10	45%	0.277
	point AND movement	2	9%	
	twist hand right (and point)	4	18%	
	push button	3	14%	
	open gesture (and point)	2	9%	
	grab	1	5%	

Other Observations

In other user generated gesture studies (e.g. Wobbrock et al. [2009]; Kray et al. [2010]; Fikkert et al. [2010]) the authors note interesting observations about the generated gestures which are also observed in this study. These observations are presented below.

Pointing

As reported in other studies (e.g. Wobbrock et al. [2009]), participants in our study often proposed a "pointing" freehand gesture for different interaction and user tasks. This was either as a method to indicate the object on which they were performing the freehand gesture (e.g. *that TV* or *that document*) or used as the whole interaction.

This might suggest that pointing is an import freehand gesture for participants to indicate the start or end of the interaction e.g. "on that object perform this action" or "perform this action on that object". Alternatively, a "pointing" freehand gesture might be used as a default freehand gesture for interaction and user tasks unfamiliar to participants. That is, pointing might be a symptom of participants not articulating the specific meaning of the task through the freehand gesture.

Its a Windows (and iPhone) World

Wobbrock et al. [2009] report that participants often generated gestures which had a direct relationship to the interactions performed on a desktop. This was also observed in our study. For example, a freehand gesture proposed for the *Delete* interaction, and corresponding user tasks, is “draw an X” which is the X button on a window which closes (or removes from view) an application or document. Similarly, for the interaction tasks *Zoom In* and *Zoom Out* some participants proposed a “pinching” freehand gesture similar to that used in multi-touch user interfaces on smartphones or tablets.

As Wobbrock et al. report it is clear how influential the desktop is for participants when thinking of how to interact with devices and applications. It is also clear how comparatively new multi-touch user interfaces can also influence participants thinking of gestural interactions.

Dichotomous Referents, Reversible Gestures

Dichotomous Referents, Reversible Gestures is reported by Wobbrock et al. [2009] as an important design consideration resulting from their studies on user generated gestures where participants “generally employed reversible gestures for dichotomous referents”.

This pattern is also observed in our study where “reversible” freehand gestures are proposed by participants for dichotomous tasks. For example, for the interaction task *Open* participant propose an “open a book” freehand gesture and propose the reverse “close a book” freehand gesture for the dichotomous interaction task *Close*. Similarly, for the interaction tasks *Zoom In* and *Zoom Out* the predominant features of the freehand gestures proposed by participants are a movement “apart” and “inwards”.

As reported by Wobbrock et al., this pattern of reversible freehand gestures for dichotomous referents is an important design consideration when selecting freehand gestures.

Performance of Freehand Gestures

Finally, participants performed freehand gestures in a variety of directions and orientations depending on how they visualised the devices or applications they might be interacting with. For example, the freehand gestures proposed for the *Select* interaction task were often performed in different directions depending on where the participant imagined the target object to be located. Similarly, participants agree that to perform the interaction task *Zoom Out* both hands should "move apart". However, participants are unsure whether this should be performed flat, moving forwards or moving backwards from the imagined interface or object.

3.1.4 Proposing a Freehand Gesture Set

As discussed in Section 3.1.2, we adopt the guessability or agreement maximisation procedure proposed by Wobbrock et al. [2005, 2009]. To select freehand gestures we maximise the suitability of the proposed freehand gestures. To calculate suitability we examine three complimentary metrics - 1. the number of times a freehand gesture is proposed by the participants, 2. agreement scores and 3. guessability scores. Additionally, we maximise the suitability of a freehand gesture across both interaction tasks and user tasks. That is, we maximise consensus between users that the proposed freehand gesture is suitable to perform the generalised interaction (e.g. *Open*, *Stop*, *Show Me*) as well as for an instance of this freehand gestures use on an imagined interface or object (e.g. *open a document*, *stop a video*, *show me my location*).

To demonstrate this approach in the reminder of this section we detail the selection of freehand gestures for the example interaction tasks in Table 3.3.

Open and Stop

For the interaction tasks *Open* and *Stop* the majority of participants propose one freehand gesture with only a few participants proposing alternatives. For the interaction task *Open*, the "open a book" freehand gesture is proposed by 17 of the 22 participants which has an agreement score of 0.620 and a guessability score of 77%. The "open a book" freehand gesture is also the most proposed freehand gesture for the user task *open an application*. 12 of the 22 participants propose this freehand gesture with an agreement score of 0.434 and a guessability score of 55%. Similarly, the "open a book" freehand gesture is proposed by 18 of the 22 participants for the user task *open a document*. The agreement score is 0.690 and the guessability score is 82%.

Although the "open a book" freehand gesture is proposed for other interaction tasks and user tasks (e.g. *Play* and *Turn On*), examining our three metrics of suitability indicates that this freehand gesture is the most suitable for the interaction task *Open*. Therefore, for the interaction task *Open* we select the "open a book" freehand gesture.

For the interaction task *Stop*, the "halt!" freehand gesture is proposed by 20 of the 22 participants with an agreement score of 0.831 and a guessability score of 82%. The "halt!" freehand gesture is also the most proposed for the user task *stop a video* with an agreement score of 0.521 and guessability score of 68%. Therefore, we select the "halt!" freehand gesture for the interaction task *Stop*.

Furthermore, the freehand gestures proposed by participants for both interaction tasks and users tasks can be classified as either symbolic or deictic gestures which on the continuum of gestures proposed by Kendon [2004] are emblem gestures. This suggests that the freehand gestures proposed for these interaction tasks, and corresponding user tasks, draw on the participants prior knowledge of conventionalised gestures from human communication which they apply to this new context. We suggest that these freehand gestures are easy to learn for new users because they are emblem gestures which have a high level of formalism and are highly conventionalised in human communication. However, where new users are not familiar with the cultural convention of a given freehand gesture ease of learning will be negatively impacted.

Zoom In and Zoom Out

For the interaction tasks *Zoom In* and *Zoom Out* participants propose a range of freehand gestures which typically differ in the direction or orientation of the hands however, broadly the proposed freehand gestures are similar.

For the interaction tasks *Zoom In* and *Zoom Out* the proposed freehand gestures show that participant consider that a movement “inwards” or “apart” are important to the suitability of the freehand gesture. For the interaction task *Zoom In* 12 of the 22 participants proposed a freehand gesture with a movement “apart” and 7 of the 22 participants proposed a freehand gesture with a movement “inwards”. The guessability score for the movement “apart” freehand gestures is 55% and for the movement “inwards” freehand gestures 32%.

For the interaction task *Zoom Out* 11 of the 22 participants proposed a freehand gesture with a movement “apart” and 7 of the 22 participants proposed a freehand gesture with a movement “inwards”. The guessability score for the movement “apart” freehand gestures is 55% and for the movement “inwards” freehand gestures 32%.

By maximising our three metrics of suitability only on the freehand gestures proposed for interaction tasks we would select the “movement apart” freehand gesture for the interaction task *Zoom In* as the agreement score is higher (0.308) compared to the interaction task *Zoom Out* (0.248). However, by also considering the proposed freehand gestures for the user tasks we find the reverse.

For the user task *zoom in on an image*, 11 of the 22 participants proposed a freehand gesture with a movement “inwards” and 9 of the 22 participants proposed a freehand gesture with a movement “apart”. The guessability score for the movement “inwards” freehand gestures is 50% and for the movement “apart” freehand gestures 41%. The agreement score for this user task is 0.380. Similarly, for the user task *zoom in on a map*, 10 of the 22 participants proposed a freehand gesture with a movement “inwards” and 8 of the 22 participants proposed a freehand gesture with a movement “apart”. The guessability score for the movement “inwards” freehand gestures is 46% and for the movement “apart” freehand gestures 36%. The agreement score for this user task is 0.262.

For the user task *zoom out of an image*, 13 of the 22 participants proposed a freehand gesture with a movement "apart" and 5 of the 22 participants proposed a freehand gesture with a movement "inwards". The guessability score for the movement "apart" freehand gestures is 60% and for the movement "inwards" freehand gestures 23%. The agreement score for this user task is 0.236. Similarly, for the user task *zoom out of a map*, 12 of the 22 participants proposed a freehand gesture with a movement "apart" and 5 of the 22 participants proposed a freehand gesture with a movement "inwards". The guessability score for the movement "apart" freehand gestures is 54% and for the movement "inwards" freehand gestures 28%. The agreement score for this user task is 0.202.

By explicitly considering the suitability of the proposed freehand gestures across both interaction tasks and user tasks we are able to select freehand gestures which are not only suitable to perform the generalised interaction but also for instances of the freehand gestures use on an imagined device or application.

Therefore, we select the "movement inwards" freehand gesture for the interaction task *Zoom In* in our proposed freehand gesture set. Conversely, we select the "movement apart" freehand gesture for the interaction task *Zoom Out*.

Furthermore, the freehand gestures proposed by participants for both interaction tasks and users tasks can be classified as iconic gestures which on the continuum of gestures proposed by Kendon [2004] are mime gestures. The freehand gestures proposed by participants perform manipulations with a device or application. These freehand gestures appear to be partly conventional, in that they were produced in a similar manner by all study participants. These will be referred to as semi-formal gestures for the purposes of this thesis. However, these freehand gestures might differ depending on the spatial cognition or assumed spatial frame of the participant. By explicitly considering the suitability of the proposed freehand gestures across both interaction tasks and user tasks we are better able to explore the spatial cognition or spatial frame of the participants to select the most suitable freehand gesture. However, for new users who do not conceptualise the spatial frame of interaction or share the same spatial cognition embodied in the selected freehand gesture, ease of learning will be negatively impacted.

Delete and Turn On

For the interaction tasks *Delete* and *Turn On* participants propose a wide range of different freehand gestures. However, there are no common features across the proposed freehand gestures and the most proposed freehand gestures in this group often are the most proposed freehand gestures for other interaction tasks and user tasks.

For the interaction task *Delete* 5 freehand gestures are proposed by participants and has an agreement score of 0.318. From these 5 proposed freehand gestures the "draw an X" and "throw away" freehand gestures are proposed most often. The "draw an X" freehand gesture is proposed by 9 of the 22 participants which has a guessability score of 41%. The "throw away" freehand gesture is proposed by 8 of the 22 participants which has a guessability score of 36%.

For the user task *delete an image* the "draw an X" freehand gesture is proposed by 7 of the 22 participants with a guessability score of 32% and the "throw away" freehand gesture is proposed by 8 of the 22 participants with a guessability score of 36%. The agreement score for this user task is 0.260.

For the user task *delete a piece of text* the "draw an X" freehand gesture is proposed by 8 of the 22 participants with a guessability score of 36% and the "throw away" freehand gesture is proposed by 7 of the 22 participants with a guessability score of 32%. The agreement score for this user task is 0.198.

The agreement scores for the interaction task *Delete* and the user tasks *delete an image* and *delete a piece of text*, when compared to the other agreement scores in this study, are average to low. This indicates that participants do not have a strong consensus as to the most suitable freehand gesture for this interaction task and the corresponding user tasks. Similarly, the guessability scores indicate that the most proposed freehand gestures are not easily guessable by new users in the absence of any training.

However, by considering the freehand gestures proposed for both the interaction task *Delete* and user tasks *delete an image* and *delete a piece of text*, we can be more confident in our selection of the most suitable freehand gesture. Therefore, we select the "draw an X" freehand gesture as the freehand gesture for the interaction task *Delete*.

For the interaction task *Turn On*, 7 freehand gestures are proposed by participants and has an agreement score of 0.231. From these 7 proposed freehand gestures the "point" freehand gestures is proposed most often. This "point" freehand gesture is already selected for the interaction task *Select* so the next most proposed freehand gesture is "rotate hand right" which is proposed by 5 of the 22 participants with a guessability score of 23%.

For the user task *turn on a TV*, 6 freehand gestures are proposed by participants and has an agreement score of 0.277. Again the most proposed freehand gesture is "point" which has already been selected. The next most proposed freehand gesture is "rotate hand right" which is proposed by 4 of the 22 participants with a guessability score of 18%.

Therefore, we select the "rotate hand right" freehand gesture as the freehand gesture for the interaction task *Turn On* in our proposed freehand gesture set.

Furthermore, the freehand gestures proposed by participants for both interaction tasks and users tasks can be classified as metaphoric gestures which on the continuum of gestures proposed by Kendon [2004] are gesticulation gestures. Gesticulation gestures are largely improvised gestures in human communication and convey ideas rather than conventions (emblem gestures) or manipulations (mime gestures). Generally, we suggest that these freehand gestures will be difficult for new users to learn.

The Proposed Freehand Gesture Set

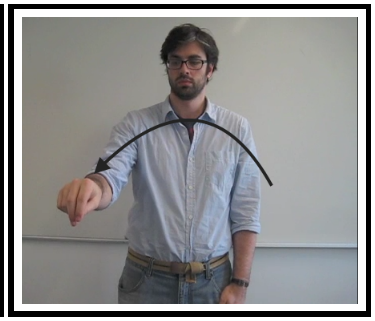
Table 3.4 shows the proposed freehand gesture set. Each freehand gesture is selected based on the maximising the three metrics of suitability across both interaction and user tasks.

Additionally, as reported by Wobbrock et al., we are able to reject one interaction task, *Go Back*, due to it being perceived as an alias to the interaction task *Move Back*. Examining the proposed freehand gestures for the interaction task *Go Back* we can see that participants in this study propose similar freehand gestures to the interaction task *Move Back*. This can also be seen in the proposed freehand gestures for the corresponding user tasks. We choose to remove *Go Back* rather than *Move Back* from our proposed freehand gesture set as *Move Back* and *Move Forward* are dichotomous interaction tasks with reversible freehand gestures. As Wobbrock et al. [2009] state, these dichotomous referents and reversible gestures, are important design considerations when defining an gesture set.

Table 3.4: Selected Freehand Gestures

Interaction Task	**Freehand Gesture Made**	**Gesture Category**
Move	movement from side to side	A
Select	point	A
Stop	halt! sign	A
Pick Up	grasp and pick up	A
Open	movement outwards like a book	A
Close	movement inwards like a book	A
Drop	open hands and a movement down	A
Zoom Out	movement from the user outwards	B
Zoom In	movement forwards towards a point	B
Move Forward	left to right movement	B
Move Back	right to left movement	B
Delete	draw an X	C
Search	circle with a tail (like the letter Q)	C
Go To	sideways movement	C
Show Me	shrug/hands open gesture	C
Turn Off	turn of the wrist (left/anti-clockwise)	C
Turn On	turn of the wrist (right/clockwise)	C
Play	circle	C

(i) Move - start



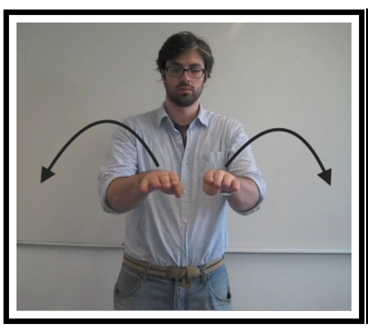
(ii) Move - end

(iii) Select

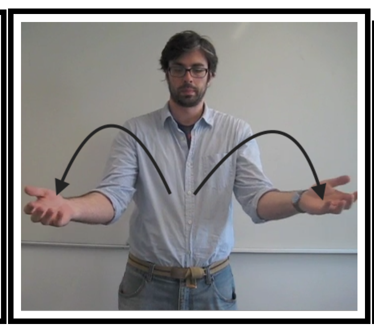
(iv) Stop

(v) Pick Up - start

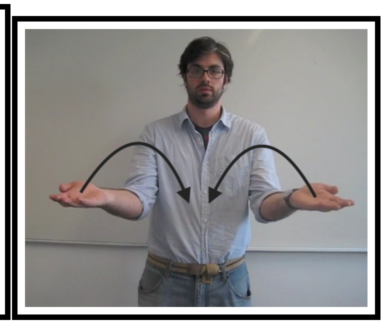
(vi) Pick Up - end



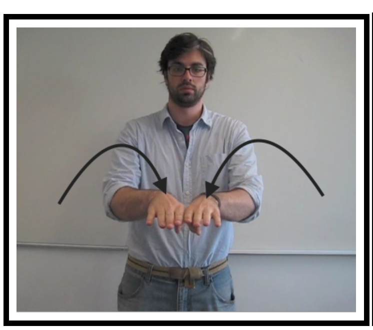
(vii) Open - start



(viii) Open - end



(ix) Close - start



(x) Close - end

(xi) Drop - start

(xii) Drop - end

Figure 3-1: Freehand Gestures Selected from the User Generation Study

(xiii) Zoom Out - start

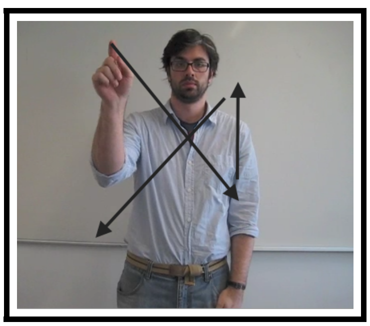
(xiv) Zoom Out - end

(xv) Zoom In - start

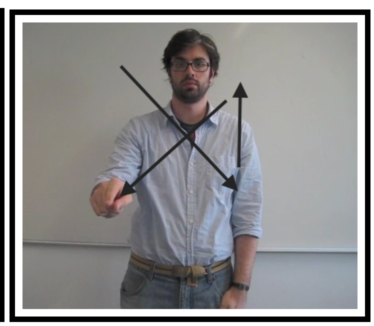
(xvi) Zoom In - end

(xvii) Move Forward - start

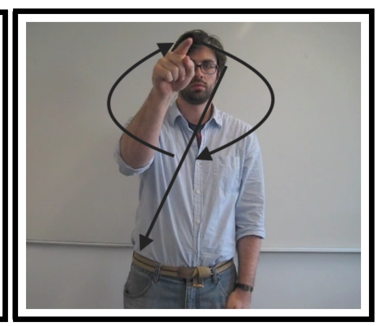
(xviii) Move Forward - end



(xix) Delete - start

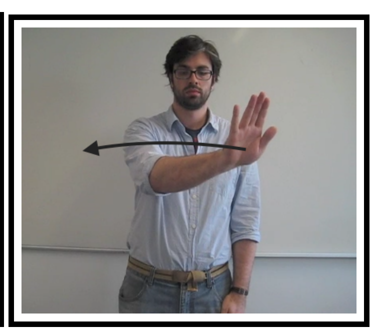


(xx) Delete - end



(xxi) Search - start

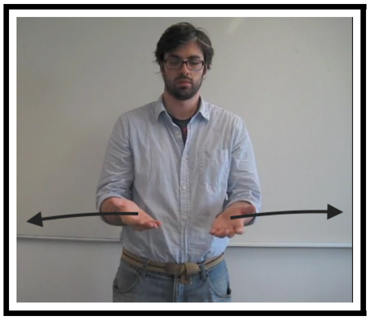
(xxii) Search - end



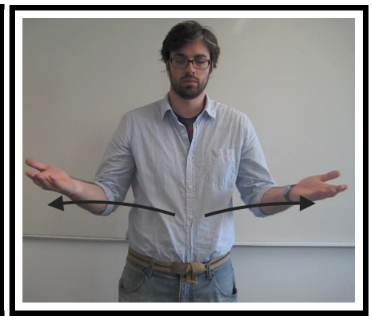
(xxiii) Go To - start

(xxiv) Go To - end

Figure 3-1: Freehand Gestures Selected from the User Generation Study (continued)



(xxv) Show Me - start



(xxvi) Show Me - end

(xxvii) Turn On - start

(xxviii) Turn On - end

(xxix) Turn Off - start

(xxx) Turn Off - end

(xxxi) Play

Figure 3-1: Freehand Gestures Selected from the User Generation Study (continued)

3.1.5 Discussion

The study presented above builds on the work by Wobbrock et al. [2005, 2009]; Fikkert et al. [2010]; Kray et al. [2010]; Ruiz et al. [2011] and presents a user generated freehand gesture study where participants are asked to proposed freehand gestures to perform different tasks across devices and applications. Additionally, the study builds on the literature which suggests that by drawing on the prior knowledge and experience of learners the time taken to learn new material can be reduced (Salomon and Perkins [1989]; Bransford [2000]). That is, by drawing on the prior knowledge and experience of potential end users, the selected freehand gestures support the mechanism of transfer of learning - learning to automaticity.

Freehand gestures are selected by maximising three complimentary metrics of suitability - 1. the number of times a freehand gesture is proposed by the participants, 2. an overall agreement score i.e. the consensus between all participants that the proposed freehand gestures are suitable for the given task and 3. guessability scores for each freehand gesture proposed by participants.

Additionally, to select a freehand gesture for an interaction task, we maximise the suitability of a freehand gesture across both the interaction task (e.g. *Open*) and user tasks (e.g. *open a document* and *open an application*). The advantage to this approach is that we maximise consensus between participants that the proposed freehand gesture is suitable to perform the generalised interaction as well as an instance of this freehand gestures use on an imagined device or application. This approach is particularly helpful where (i) the proposed freehand gestures differ in the direction or orientation of the hands and (ii) participants propose a wide range of different freehand gestures.

From the analysis of the proposed freehand gestures there emerged three groups of interaction tasks which group together proposed freehand gestures based on differences in their suitability (see Section 3.1.2). A Kruskal-Wallis test reported that there was a statistically significant difference between these emerging groups for each of our metrics of suitability. Furthermore, the observations made regrading the both the metrics of suitability and the types of proposed freehand gestures are also evident in the proposed freehand gestures for corresponding user tasks.

Therefore, from these emerging groups of interaction tasks we propose three Gesture Categories - A, B and C. These Gesture Categories group together selected freehand gestures based on 1. the differences in the calculated metrics of suitability when considering both interaction and user tasks (high, medium and low), 2. the classification of the freehand gesture most proposed by participants (symbolic/deictic , iconic and metaphoric) and 3. the categorisation of the selected freehand gestures based on the continuum of gestures proposed by Kendon [2004] (emblem, mimes and gesticulation) which correspond to different levels of formalism in human communication (highly formal, semi-formal and largely improvised).

We suggest that the freehand gestures in these Gesture Categories correspond to high, medium and low levels of suitability for the given interaction tasks and corresponding user tasks. Where, we expand our definition of suitability to include not only suitability as calculated by the number of proposed freehand gestures, agreement scores and guessability scores but also, the potential prior experience from which new users might draw on when learning a new freehand gesture. That is, based on the continuum of gestures in human communication proposed by Kendon [2004], selected freehand gestures can be categorised based on the different levels of formalism (i.e. highly formal emblem gestures, semi-formal mime gestures and largely improvised gesticulation gestures) and therefore the potential prior experience and familiarity of the user with the freehand gesture as used in everyday human communication.

The literature suggests that the more suitable a freehand gesture (often based on the number of proposed freehand gestures, agreement scores or guessability scores, as opposed to the expanded definition of suitability presented above) the easier it is to learn (e.g. Wobbrock et al. [2009]; Nacenta et al. [2013]). Therefore, in the next section we report a follow up study investigating the ease of learning of the proposed freehand gesture set. This follow up study investigates if, as indicated in the literature, suitability does indeed indicate ease of learning of freehand gestures. Additionally, this study investigates if Gesture Categories do provide (i) an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (ii) an indication as to the ease of learning of a freehand gesture.

3.2 Follow Up Ease of Learning Study

In this section we report a follow up study investigating the ease of learning of the freehand gesture set proposed in Section 3.1. The results of this study examine if, as indicated in the literature, suitability does indeed indicate ease of learning of freehand gestures. Additionally, this study investigates if the proposed Gesture Categories do provide (i) an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (ii) an indication as to the ease of learning of a freehand gesture.

3.2.1 Method

Design

A within subjects experimental design was followed. The independent variable was Gesture Category with 3 levels (A, B and C) which indicates the different levels of suitability (high, medium and low respectively) of the freehand gestures.

The primary dependent variables were the number of errors in 1. retention and 2. accuracy of performance. An error in retention was recorded if the participant forgot or performed the wrong freehand gesture therefore, requiring them to be prompted as to the correct freehand gesture. Incorrect performance was assessed as the freehand gesture not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training.

The other dependent variable was the fit between the freehand gesture and the task, as perceived by the participants. This was measured by the participants rating on a scale of 1..20 (where 1 is not well matched and 20 is very well matched) *"how much you felt it action of the gesture related to the function of the gesture"* (i.e. the suitability of the freehand gesture for the given interaction task).

Hypotheses

In Section 3.1 we propose a freehand gesture set where we select freehand gestures by maximising suitability across both interaction tasks and user tasks. That is, we maximise consensus between participants that the proposed freehand gesture is suitable to perform the generalised interaction as well as for an instance of this freehand gestures use on an imagined interface or object. The literature suggests that the more suitable a freehand gesture the easier it is to learn. Therefore we hypothesis that,

H1: The better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture

Furthermore, in Section 3.1 we propose three Gesture Categories (A, B and C) which group together freehand gestures with different levels of suitability (high, medium and low respectively). To examine if the Gesture Categories do provide an indication as to the suitability of a freehand gesture we hypothesised that,

H2: Category A gestures will be rated by our participants as a better fit to their respective tasks than Category B gestures, which in turn will be rated as having better task fit than Category C gestures

Finally, we predict that freehand gestures in Category A will be be easier to learn than freehand gesture in Category B which, are easier to learn than freehand gesture in Category C. Therefore we hypothesised that,

H3: Category A gestures will have in fewer errors in learning than gestures in Category B, which in turn will have fewer errors in learning than gestures in Category C

Participants

Eighteen participants took part in the study, aged from 20 to 44 with a mean age of 30. 14 of the participants were male and 4 were female. All participants were right-handed. All participants were recruited from around the University of Bath. No reward was given for their participation.

Procedure

Participants were run individually. The study had three phases; Training Phase, Interference Task Phase and Learning Assessment Phase. In the Training Phase participants were trained on a sub set of freehand gestures in the freehand gesture set proposed in Section 3.1 (see Table 3.5). Next participants completed an interference task. Finally, in the Learning Assessment Phase, participants were read aloud a task and asked to perform a freehand gesture, from those they had been trained on, that they would use to perform that task. Participants were not given any physical devices on which to perform the freehand gesture and the study took place in a lab where no devices were present apart from a laptop and video camera used to record the freehand gestures made by participants in each phase for later analysis. All of the materials used in this study can be found in Appendix A.2.

Training Phase

Participants were trained on the freehand gestures in Table 3.5. Each participant was demonstrated the freehand gesture by the experimenter. The participant was then asked to perform this freehand gesture correctly 10 times to the experimenter. The experimenter ensured that the participant performed the freehand gesture correctly i.e. the freehand gesture performed by the participant had the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated. This procedure was repeated for all freehand gestures in the gesture set. The order in which each participant was trained on the freehand gestures was randomised.

Interference Task Phase

Upon completion of the Training Phase, each participant performed an interference task. The experimenter read aloud a new set of tasks (see Table 3.6) and asked the participant to generate a freehand gesture(s) they thought would best perform that task. Participants were encouraged to be as creative as possible in generating these new freehand gestures and they were not constrained to those they had just been shown. Each participant generated freehand gestures for 15 new tasks, taking a minimum of 5 minutes to complete.

Learning Assessment Phase

In the final phase of the experiment, the experimenter read aloud a task and participants were asked to perform the freehand gesture, from those they had been trained on, they thought would best perform that task. This was repeated for all tasks in Table 3.7. The experimenter recorded errors in 1. retention and 2. accuracy of performance. An error in retention was recorded if the participant forgot or performed the wrong freehand gesture therefore, requiring them to be prompted as to the correct freehand gesture. Incorrect performance was assessed as the freehand gesture not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training.

Finally, participants completed a questionnaire on their experience of the freehand gestures and tasks used in the study. In addition, they were asked for their perceptions on the fit between the freehand gesture and the task.

Table 3.5: Freehand Gestures Used in the Follow Up Ease of Learning Study (A Sub Set of the Freehand Gestures from Table 3.1).

Freehand Gesture	**Textual Description of Gesture**
Select	point
Open	movement outwards like a book
Close	movement inwards like a book
Pick Up	grasp and pick up
Drop	open hands and a movement down
Zoom In	movement forwards towards a point
Zoom Out	movement from the user outwards
Move Forward	left to right movement
Move Back	right to left movement
Search	circle with a tail (like the letter Q)
Show Me	shrug/hands open gesture
Delete	draw an X

Table 3.6: Interference Tasks for Follow Up Ease of Learning Study.

Task No.	**Task**
1	Go back
2	Go back to the previous image
3	Go back to the previous image and move it to another device
4	Go to an image
5	Go to your media and find a video
6	Move an application from one device to another
7	Move a document from one device to another
8	Pause your music
9	Play a video
10	Play your music through the speakers of the TV
11	Stop a video
12	Turn off a TV
13	Turn off your privacy settings
14	Turn on a TV
15	Turn on your location sharing profile

Table 3.7: User Tasks Presented to Participants in the Learning Assessment Phase of the Follow Up Ease of Learning Study - Freehand Gestures to be Performed by Participants Highlighted in Bold

Task No.	Task
1	**CLOSE** a document and **DELETE** it
2	**CLOSE** an application
3	**DELETE** a piece of text
4	**DELETE** an image and **OPEN** another
5	**DROP** a review about a cafe at this location
6	**DROP** some media
7	**MOVE BACK** to the previous page in a document and **SELECT** some text
8	**MOVE BACK** in the video a few seconds
9	**MOVE FORWARD** in a collection of images and **OPEN** one
10	**MOVE FORWARD** in the video a few seconds
11	**OPEN** an application
12	**OPEN** a document and **SELECT** a table in the document
13	**PICK UP** a web link from another users device
14	**PICK UP** some media
15	**SEARCH** for an image and **DELETE** it
16	**SEARCH** a video
17	**SELECT** a document and **OPEN** it
18	**SELECT** a point of interest
19	**SHOW ME** my location and **ZOOM IN** on the map
20	**SHOW ME** information about this cafe
21	**ZOOM IN** to a map and **SELECT** an marker
22	**ZOOM IN** to a image
23	**ZOOM OUT** of a map
24	**ZOOM OUT** of an image and **SELECT** a feature

3.2.2 Results

We present the results of this study in three parts. The first part reports the results examining if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture (H1). Next we report the results examining if the Gesture Categories proposed in Section 3.1 do provide an indication as to the suitability of a freehand gesture (H2). Finally, we report the results examining if the indication of the suitability of a freehand gesture provided by its Gesture Category also provides an indication as to the ease of learning of the freehand gesture (H3).

Suitability and Ease of Learning

The results reported in this section address if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture (H1). We examine the relationship between our participants rating of freehand gestures in response to the question *"how much you felt it action of the gesture related to the function of the gesture"* and the number of errors in learning made (i.e. the combined number of errors in retention and accuracy of performance). A Pearson product-moment correlation showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased ($r(214)=-0.295$, $p<0.001$). This result confirms our hypothesis H1 that suitability does indeed indicate ease of learning of freehand gestures.

Gesture Categories and the Suitability of Freehand Gestures

The results reported in this section address if the Gesture Categories proposed in Section 3.1 do provide an indication as to the suitability of a freehand gesture (H2).

Table 3.8 shows a summary of the ratings participants gave for each freehand gesture in this study in response to the question *"how much you felt it action of the gesture related to the function of the gesture"*. From this table we can see that participants rated freehand gestures in Category A as well matched their tasks. Category B freehand gestures were, as predicted, were not rated as highly as Category A freehand gestures but were rated as a better fit to the task than freehand gestures in Category C. The notable exception here was *Delete*.

The mean rating of the fit between the freehand gesture and the task of freehand gestures in Category A is 17.74 (*sd*=2.55), for Category B is 14.97 (*sd*=4.77) and for Category C is 12.43 (*sd*=5.95).

To further examine this relationship we conducted a one-way ANOVA. The results report that there was a statistically significant difference in the rating of the fit between the freehand gesture and the task between Gesture Categories ($F=25.701$, $p<0.001$). Post hoc Tukey tests indicated that freehand gestures in Category A were rated significantly higher than freehand gestures in Category B (p<0.001) and freehand gestures in Category B were rated significantly higher than freehand gestures in Category C (p=0.004).

These results confirm our hypothesis H2, that Gesture Categories do provide an indication as to the suitability of a freehand gesture. That is, Category A freehand gestures were rated higher in response to the question *"how much you felt it action of the gesture related to the function of the gesture"*, than Category B freehand gestures which were rated higher than Category C freehand gestures.

Table 3.8: Participant Rating of the Suitability (i.e. Rating of the Fit Between the Freehand Gesture and the Task) of the Freehand Gestures in the Follow Up Ease of Learning Study.

Gesture	**Category**	**Low (1-7)**	**Average (8-14)**	**High (15-20)**	**Mean Rating**
Select	A	0	1	17	18.61 (*sd*=3.80)
Pick Up	A	0	1	17	18.11 (*sd*=1.94)
Open	A	0	2	16	17.89 (*sd*=2.30)
Drop	A	0	0	18	17.83 (*sd*=1.76)
Close	A	1	2	15	16.28 (*sd*=3.80)
Move Forward	B	2	2	14	15.39 (*sd*=5.11)
Move Back	B	2	2	14	15.17 (*sd*=5.08)
Zoom In	B	1	6	11	14.67 (*sd*=4.63)
Zoom Out	B	1	6	11	14.67 (*sd*=4.63)
Delete	C	0	2	16	17.50 (*sd*=2.75)
Search	C	4	9	5	11.22 (*sd*=4.82)
Show Me	C	10	3	5	8.56 (*sd*=5.91)

Gesture Categories and Ease of Learning

The results reported in this section address whether the indication of the suitability of a freehand gesture provided by its Gesture Category also provides an indication as to the ease of learning of the freehand gesture (H3).

Ease of learning was assessed as the number of errors in 1. retention and 2. performance. Table 3.9 shows the number of errors made by all participants in retention and performance. From this table we can see that the number of errors made by participants was very low. In particular the number of errors in performance for all freehand gestures (regardless of Gesture Category) are particularly low. Given the time between the Training Phase and the Learning Assessment Phase of the study this might not be unexpected. However, the data collected does indicate potential trends which are in line with the proposed relationship between the Gesture

Categories and the ease of learning of freehand gestures.

Freehand gestures in Category A, as expected, produced the fewest errors in both retention and performance. However, there was a larger number of errors in retention for the *Close* freehand gesture compared to the other freehand gestures in Category A. Inspecting the data further revealed that this was often due to participants performing the *Delete* freehand gesture.

Freehand gestures in Category B produced the highest errors in performance with participants often performing a freehand gesture using the wrong hand (e.g. using the right hand to perform the *Move Forward* freehand gesture instead of the left) or direction (e.g. moving the hand from right to left to perform the *Move Forward* freehand gesture rather than left to right).

Freehand gestures in Category C produced the highest number of errors in retention. Inspecting the data further indicates that this was primarily caused by participants forgetting the freehand gesture rather than performing the wrong freehand gesture.

Examining the errors in retention, a one-way ANOVA test reports that there was a statistically significant difference in the number of errors in retention between Gesture Categories ($F=16.930$, $p<0.001$). Post hoc Tukey tests indicated that freehand gestures in Category C produced significantly higher errors in retention than freehand gesture in Category A ($p<0.001$) and Category B ($p<0.001$). There was no such significant different between freehand gestures in Category A and Category B ($p=0.754$).

However, examining the errors in performance, a one-way ANOVA test reports that there was not a statistically significant difference in the number of errors in performance between Gesture Categories ($F=1.521$, $p=0.221$). Although not statistically significant, examining the mean number of errors in performance indicates that Category B produced more errors in performance than Category A and Category C.

These results suggest that participants forgetting previously learnt freehand gestures is the primary factor influencing the ease of learning of freehand gestures.

Furthermore, in line with the division of freehand gestures into Gesture Categories, freehand gestures in Category C produced more errors in retention than freehand gestures in Category A and Category B. That is, from the original generation study, the freehand gestures in Category C were selected from a wide range of proposed freehand gestures and can be classified as gesticulation gestures which are largely improvised gestures and convey the ideas of the participants who originally generated the freehand gestures rather than conventions (Category A, emblem gestures) or manipulations (Category B, mime gestures).

Again in line with the division of freehand gestures into Gesture Categories, freehand gestures in Category B produced more errors in performance than freehand gestures in Category A and C. That is, from the original generation study, freehand gestures in Category B were were selected from a small number of proposed freehand gestures which typically differed in the direction and orientation of the hands and can be categorised as mime gestures which are semi-formal gestures which typically convey actions on a given object. Freehand gestures in Category B are likely to be similar between the generating participants and new users however, we might expect errors in performance as a result of differing spatial cognition or assumed spatial frame between the generating participants and new user.

These results suggest that we can partially confirm our hypothesis H3. H3 is partially confirmed as, Category A and Category B freehand gestures produce fewer errors in retention than freehand gestures in Category C. Where errors in retention is the primary cause of errors in learning.

Table 3.9: Errors Made by Participants in Retention and Performance of Freehand Gestures in the Follow Up Ease of Learning Study.

Freehand Gesture	**Gesture Category**	**No. Errors: Retention**	**No. Errors: Performance**
Drop	A	0	0
Open	A	1	0
Select	A	2	1
Pick Up	A	2	2
Close	A	5	0
Zoom Out	B	1	0
Move Back	B	1	1
Move Forward	B	1	2
Zoom In	B	2	1
Delete	C	5	0
Search	C	6	0
Show Me	C	12	0

3.2.3 Discussion

The study presented investigates the ease of learning of the freehand gesture set proposed in Section 3.1. The study investigated if, as indicated in the literature, suitability does indeed indicate ease of learning of freehand gestures. Participants were trained on a sub set of the proposed freehand gesture set (see Table 3.5) and ease of learning was assessed. Ease of learning was assessed as the number of errors in 1. retention and 2. accuracy of performance.

The results of this study confirm that, as indicated in the literature, suitability does indeed indicate ease of learning of freehand gestures. Examining the relationship between the participants rating of the fit between the freehand gesture and the task (i.e. the suitability of the freehand gesture for the given interaction task) and the number of errors in learning showed that, as this rating increased the number of errors in learning decreased.

Additionally, this study investigates if Gesture Categories do provide (i) an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (ii) an indication as to the ease of learning of a freehand gesture.

The results of this study show that Gesture Categories do provide an indication as to the suitability of a freehand gesture. Freehand gestures in Category A were rated as more suited to the given interaction task, than freehand gestures in Category B which in turn were rated more suited to the given interaction task than freehand gestures in Category C.

Finally, the results of this study indicated that errors in retention was the primary cause of errors in learning. Furthermore, the results suggest that Gesture Categories do provide a broad indication as to the ease of learning of freehand gestures. Interestingly, in line with the division of freehand gestures into Gesture Categories, freehand gestures in Category C produced the most errors in retention and freehand gestures in Category B produced the most errors in performance. This might suggest that the broad indication of ease of learning indicated by the Gesture Categories might be refined to, freehand gestures in Gesture Category A indicate both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

Overall, this study reports two important findings. The first finding is the relationship between participant rating of the fit between the freehand gesture and the task and the number of errors in learning. This relationship provides a method of evaluating, and comparing, the suitability of a given freehand gesture which is an indication of its ease of learning. For example, we could evaluate and compare different user generated freehand gestures and designer generated freehand gestures so that the most suitable is selected. Similarly, different user generated freehand gestures could be evaluated and compared again, so that the most suitable is selected.

The second finding is the broad indication provided by the Gesture Categories of the perception of suitability and the ease of learning of freehand gestures for new users. Gesture Categories group together freehand gestures based on the metrics of suitability calculated as part of the freehand gesture generation study as well as observations regarding the types of these proposed freehand gestures.

The results of the study indicate that Gesture Categories do provide an indication as to the perception of suitability of the freehand gestures for users other than by whom they were generated. That is, high, medium and low perceptions of suitability for Category A, B and C respectively. Furthermore, in line with the relationship reported above between the perception of suitability and ease of learning, Gesture Categories provide a broad prediction as to the ease of learning of the freehand gestures in that Category. That is, high, medium and low levels of ease of learning for Category A, B and C respectively.

Finally, in line with other gesture generation studies (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]), the results of this study highlight that particular freehand gestures are difficult to learn. For these freehand gestures there is a need to provide users with additional support when learning these freehand gestures.

Gesture Categories provide designers with a broad prediction of the ease of learning of groups of freehand gestures which could be used to focus where additional support is provided to new users when learning freehand gestures. Furthermore, the results of this study suggest that Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance. These latter observations provide designers with additional information to help further focus the type of additional support provided to new users when learning freehand gestures.

3.3 Discussion

Building on the research on transfer of learning (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]), user generated gesture studies (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]) and the literature suggesting a link between suitability and ease of learning (e.g. Wobbrock et al. [2005]; Nacenta et al. [2013]), the studies presented in this chapter investigate how, by drawing on the prior knowledge and experience of end users, we can support the learning of freehand gestures to automaticity.

The first study presented is a user generated freehand gesture study where participants propose freehand gestures to perform different tasks designed for interaction across different devices and application. From this study we propose a set of freehand gestures.

Freehand gestures are selected by maximising three metrics of suitability - 1. the number of times a freehand gesture is proposed by the participants, 2. agreement scores and 3. guessability scores. These metrics were chosen as, the number of times a freehand gesture is proposed by the participants and the agreement score, provide an indication as to the consensus between participants on how suitable the most proposed freehand gesture is for the given task. The guessability score provides an indication as to how easily guessable a freehand gesture is in the absence of any training.

Additionally, we maximise the suitability of freehand gestures across both interaction tasks (e.g. *Open, Stop, Show Me*) and user tasks (e.g. *open a document, stop a video, show me my location*). The primary advantage to this approach is that we maximise consensus between participants that the proposed freehand gesture is suitable to perform the generalised interaction as well as an instance of this freehand gestures use on an imagined device or application. A further advantage is that this approach is particularly helpful when selecting the most suitable freehand gestures where (i) the proposed freehand gestures differ in the direction or orientation of the hands and (ii) participants propose a wide range of different freehand gestures.

Emerging from observations of the proposed freehand gestures were three Gesture Categories (A, B and C) which group together selected freehand gestures based on their different levels of suitability (high, medium and low respectively). Where, we expand our definition of suitability to include not only, the metrics presented above, but also the potential prior experience new users could draw on when learning a new freehand gesture. That is, based on the continuum of gestures in human communication proposed by Kendon [2004], selected freehand gestures can be categorised based on the different levels of formalism (i.e. highly formal emblem gestures, semi-formal mime gestures and largely improvised gesticulation gestures) and therefore, the users' potential prior experience and familiarity with the freehand gesture as used in everyday human communication.

The second study builds on the results of the first study and investigates if, as indicated in the literature, suitability does indeed indicate ease of learning of freehand gestures. Additionally, the second study investigates if Gesture Categories do provide (i) an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (ii) an indication as to the ease of learning of a freehand gesture.

The results confirm that suitability does predict the ease of learning of freehand gestures. Examining the relationship between the participants rating of the fit between the freehand gesture and the task and the number of errors in learning showed, that as this rating increased the number of errors in learning decreased.

Furthermore, the results show that Gesture Categories do provide an indication as to the perception of suitability of a freehand gesture for new users. Category A freehand gestures were rated as more suited to the interaction tasks than Category B freehand gestures which in turn were rated more suited to the interaction tasks than Category C freehand gestures.

Similarly, the results show that Gesture Categories do provide a broad indication as to the ease of learning of freehand gestures for new users. Interestingly, in line with the division of freehand gestures into Gesture Categories, freehand gestures in Category C produced the most errors in retention and freehand gestures in Category B produced the most errors in performance. This might suggest that the broad indication of ease of learning indicated by the Gesture Categories might be refined to, freehand gestures in Gesture Category A indicate both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

From these two studies a number of important finding emerge. The first is that, in line with other gesture generation studies (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]), particular freehand gestures are more suitable and easier to learn than others. In supporting the mechanism of transfer of learning - learning new material to automaticity - we might address this challenge by examining further the alternative freehand gestures proposed by participants. We might also conduct further user generated freehand gesture studies, presenting participants with more user tasks, from which we might be able to find better consensus on the suitability of a proposed freehand gesture.

However, it is unlikely that all freehand gestures selected will be equally suitable and equally easy to learn. Indeed for some interaction tasks, given the abstractness or unfamiliarity of the type of interaction in an unfamiliar or unknown context, it might not be possible to generate, and consequently select, a highly suitable and easy to learn freehand gesture. This suggests that there is a need to provide the user with additional support when learning these freehand gestures.

Secondly, Gesture Categories provide a broad prediction to designers of the likely perceptions of suitability and ease of learning of freehand gestures for new users. This prediction could be used to focus where additional support is provided to new users when learning freehand gestures. Furthermore, the results presented suggest that Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance. These observations could provide designers with additional information to help further focus the type of additional support provided to new users when learning freehand gestures.

Finally, the relationship between the fit between the freehand gesture and the task (i.e. the perceived suitability of the freehand gesture for the task) and the number of errors in learning provides a way of evaluating and comparing freehand gestures. For example, designers might compare two (or more) proposed freehand gestures in a study similar to that described in study two, with the ratings of the fit between the freehand gesture and the task used to select the most suitable freehand gesture. Similarly, designers might conduct an online survey where participants are shown different freehand gestures and asked to rate the fit between the freehand gesture and the task.

Furthermore, this relationship could provide a way of evaluating the additional support provided to users when learning freehand gestures. For example, does one method of additional support prove effective for those freehand gesture where the predicted suitability is low but adversely effects those freehand gestures where the predicted suitability is high?

3.3.1 Limitations

One potential limitation to the studies presented in this chapter is that all participants are right-handed. In both the generation study as well as the ease of learning study the differences between right-handed and left-handed participants is not explored. For example, do left-handed participants generate freehand gestures which are mirrors of those generated by right-handed participants? Similarly, do left-handed participants tend to perform learnt freehand gestures as mirror images to the training they have received and thus produce a error in performance?

The literature on motor learning suggest that learning to perform a skill with one hand (either the dominant or non-dominant hand) does not have a significant detrimental effect on the performance of the same skill with the other hand (e.g. Hicks [1974]; Halsband [1992]; Morton et al. [2001]). This generalisability of skill performance across both hands has been termed *intermanual* or *bimanual* transfer and might suggest that learning to perform a freehand gesture with one hand does not significantly reduce performance of the same freehand gesture with the other hand.

However, as Annett and Bischof [2013] highlight, for gestural interaction it is important to understand if this *intermanual* transfer is symmetric or asymmetric. Symmetric transfer is when transfer does not depend on the hand used during skill acquisition whereas asymmetric transfer is does. In motor skill learning, the literature suggests that *intermanual* transfer is task dependant. That is, tasks such as catching (e.g. Morton et al. [2001]) or placing items on a pegboard (e.g. Schulze et al. [2002]) are symmetric but letter or figure drawing are asymmetric (e.g. Hicks [1974]; Halsband [1992]). There is however, little agreement in the literature as to why certain motor skills are symmetric or asymmetric.

For gestural interaction there is little research on *intermanual* transfer, in particular whether gesture learning is symmetric or asymmetric. Annett and Bischof [2013] investigate this challenge for stroke based gestural interactions. The results reported by Annett and Bischof indicate that stroke based gestures transfer symmetrically with similar accuracy of performance being attained when performing stroke gestures with the opposite hand to that they were learnt with. Furthermore, Annett and Bischof report no effect of the shape of the stroke gesture on the accuracy of performance.

Investigating *intermanual* transfer of freehand gestures as well as whether freehand gestures transfer symmetrically or asymmetrically should be further investigated, however is beyond the scope of this thesis.

Another limitation of the followup ease of learning study is the short time between the Training Phase and the Learning Assessment Phase. The literature suggests that learners are provided with opportunities for extensive practice, with multiple examples in different contexts (e.g. Salomon and Perkins [1989]; Haskell [2001]; Bransford [2000]). That is in evaluating learning we should consider learning over time. As Grossman et al. [2009] highlights, this initial and extended learning are two important metrics by which learnability should be evaluated.

To address this limitation as well as to validate these findings, the studies presented in the subsequent chapters of this thesis also examine (i) the relationship between participants rating of the fit between the freehand gesture and the task and the number of errors in learning, (ii) if the Gesture Categories do provide an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (iii) if the Gesture

Categories do provide an indication as to the ease of learning of a freehand gesture.

3.4 Chapter Summary

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). This chapter focused on the former, that is supporting the learning to automaticity of freehand gestures for new users. Specifically, the studies presented in this chapter investigated,

R01: How can we draw on the users prior knowledge and experience to support learning to automaticity?

The first study presented in this chapter was a user generated freehand gesture study where participants proposed suitable freehand gestures to perform different tasks designed for interaction across devices and applications. From this study we proposed a freehand gesture set where freehand gestures were selected by maximising three metrics of suitability (1. the number of proposed freehand gestures, 2. agreement scores and 3. guessability scores) across both interaction tasks and user tasks. We adopt this approach as it maximises consensus between participants that the proposed freehand gesture is suitable to perform both the generalised interaction, as well as, an instance of this freehand gestures use on an imagined device or application.

Emerging from our examination of the proposed freehand gestures were three Gesture Categories (A, B and C) which group together selected freehand gestures based on their different levels of suitability (high, medium and low respectively). We expand our definition of suitability to include not only, suitability as calculated by the metrics presented above but also the potential prior experience new users could draw on when learning a new freehand gesture. That is, based on the continuum of gestures in human communication proposed by Kendon [2004], selected freehand gestures can be categorised based on the different levels of formalism (i.e. highly formal emblem gestures, semi-formal mime gestures and largely improvised gesticulation gestures) and therefore, the users' potential prior experience and familiarity with the freehand gesture as used in everyday human communication.

The second study presented in this chapter investigated the ease of learning of the freehand gesture set proposed from the first study. The results of this study showed that, as indicated in the literature, suitability does indeed indicate the ease of learning of freehand gestures. Additionally, this study indicated that Gesture Categories do provide a broad indication of (i) the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (ii) the ease of learning of a freehand gesture.

With regards to the letter result, it is worth noting that errors in retention were the primary cause of errors in learning. Furthermore, the results of this study suggest that Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

Overall, the results of both studies presented in this chapter indicated that additional support is needed for users when learning freehand gestures especially, for freehand gestures which have a low rating of suitability.

The literature on transfer of learning highlights that there is a distinct advantage to supporting both of mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) as "teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations" [Salomon and Perkins, 1989, p 129]. Building on this observation, in the next chapter we investigate how to support mindful abstraction. and present a user study which investigates the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the learning of freehand gestures.

Chapter 4

Supporting Mindful Abstraction and Investigating the Learning of Freehand Gestures

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]).

In Chapter 3 we investigated how, by drawing on the prior knowledge and experience of end users, we can support the mechanism of transfer of learning - learning to automaticity. In this chapter we investigate how to support mindful abstraction and investigate the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures.

Building on this literature presented in Section 2.3.3, we investigate how we can use metaphor, introduced during pre-use training, to support the mechanism of transfer of learning - mindful abstraction. Furthermore, this chapter experimentally tests the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction), by examining the effect on the learning of freehand gestures.

In the remainder of this chapter we first detail how the metaphors used in the study were generated. Next we present a study examining the effect of metaphor, introduced during participant training, on the ease of learning of freehand gestures.

The study presented consists of two phases - *Immediate Learning Phase* and *Delayed Learning Phase*. In the *Immediate Learning Phase*, participants are trained on the freehand gesture set proposed in Chapter 3. Immediately after training, the participants learning of the freehand gestures is assessed. Learning is assessed as the number of errors in 1. retention and 2. accuracy of performance. An error in retention is recorded if the participant forgot or performed the wrong gesture therefore requiring them to be retrained. Incorrect performance is assessed as the freehand gesture not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training.

The *Delayed Learning Phase* is administered 7 days, 14 days and 21 days after the *Immediate Learning Phase*. Participants learning of the freehand gestures is again assessed.

The study presented in this chapter contributes to our research objectives by investigating how we can support the mechanism of transfer of learning - mindful abstraction. Furthermore, the study presented investigates the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures. Specifically, the study presented investigates,

R02: How can we use metaphor to support mindful abstraction?

R03: How can we support both mechanisms of transfer of learning for new users of freehand gestures?

R04: Does supporting both mechanisms of transfer of learning make freehand gestures easier to learn for new users?

4.1 Metaphor Generation

To support mindful abstraction, the literature suggests that learners are presented with metaphors or analogies which can support the learner in understanding the key principles, ideas or strategies of the taught material (Salomon and Perkins [1989]; Haskell [2001]).

As discussed in Section 2.3.3, to support learning, often across different systems, the use of metaphor in user interface design has a long history. Furthermore, the literature highlights that the choice of metaphor plays an important part in conveying key abstractions to the user and therefore, we suggest in supporting mindful abstraction.

Erickson [1990] states that when generating metaphors for user interfaces, designers should (i) find the metaphors already present in the system, (ii) fully understand the systems functionality and (iii) most importantly, understand what functions users may not understand. "Armed with this knowledge, the designer can search for metaphors that best support the areas where the users' understanding is the weakest" [Erickson, 1990, pp73].

Interface metaphors present to the user an abstraction of the system, often based on something familiar, which invites the user to apply their understanding of this abstraction to perform different tasks. As Helander et al. [1997] suggests, the use of metaphor helps to structure the users mental model by supporting the link between the users interaction with a system and their prior knowledge of familiar concepts.

Similarly, the observations of the freehand gestures generated in Chapter 3, in particular the proposed Gesture Categories and the categorisation of these freehand gestures as either emblems, mimes or gesticulations, also suggest the importance of the link between the users' interaction with a system and their prior knowledge of familiar concepts. For example, the results from the follow up study indicate that freehand gestures in Category A produce fewer errors in learning (both in retention and performance) than freehand gestures in Category B and C. Where freehand gestures in Category A are emblem gestures that seem to draw on the users' prior experiences acquired through interacting with other people and their environment in everyday life.

Furthermore, the results from the follow up study indicate that freehand gestures in Category B primarily produce errors in performance rather than errors in retention i.e. participants found it difficult to correctly perform, rather than remember, the freehand gesture for a given task. Whereas, freehand gestures in Category C primarily produced errors in retention.

Therefore, building on the observation of Erickson [1990] that designers should "support the areas where user understanding is the weakest", we suggest that for freehand gestural interaction we should support the user in understanding 1. how the use of a given freehand gesture relates to similar interactions with technology, other people or everyday life or 2. the physical features of the given freehand gesture.

The former is reflected in current approaches to the design of gestural interactions where designers often draw on familiar interaction metaphors to support learning e.g. cocktail mixing (e.g. Yoo et al. [2010]) or cultural gestures such as the *namaste* gesture (Mistry et al. [2009]). The latter builds on the observations from Chapter 3 that the spatial cognition or spatial frame differences between the generating participants and new users of freehand gestures can cause difficulties when learning freehand gestures, in particular for freehand gestures in Category B (i.e. mime gestures).

Building on these observations, we propose two types of metaphor - *task metaphor* and *performance metaphor*. A *task metaphor* explains the freehand gesture in terms of an example user task. That is, a task, operation or manipulation the user might perform with that freehand gesture on an object. For example, "as though you are widening a view" to zoom in on an image or "as though you are spinning an LP" to play a song. Where spatial information is conveyed by a *task metaphor* it conveys information about the movements or manipulations on the object. For example, for the *Turn On* freehand gesture the task metaphor might be "as though you are turning a radio dial" which may be elaborated to include a direction of movement of the dial i.e. "clockwise". Similarly, for the freehand gesture *Move Back* the task metaphor might be "as though you are scrolling backwards along a line of text".

Conversely, a *performance metaphor* describes the physical shape and movement of the freehand gesture e.g. "looks like drawing the letter V" to zoom in on an image or "looks like drawing the letter O" to play a song. Where spatial information is conveyed by a *performance metaphors* it describes movements made by the user for example, "looks like drawing the letter V" might be further elaborated with "moving downwards" or "looks like a rotating you wrist to the right" to turn on a TV.

The metaphors used in this study were generated by the author. An initial set of *task* and *performance metaphors* was proposed. This set was refined through open discussions and feedback from a number of colleagues who were independent of the research. Amendments to the proposed metaphors were discussed and adopted if all the researchers involved in the discussions agreed that the new metaphor provided a better explanation/description of the freehand gesture. Table 4.1 lists the *task metaphors* and *performance metaphors* associated with each freehand gesture.

Table 4.1: Metaphors Presented to Participants in an Ease of Learning Study. Each Freehand Gesture is Presented Alongside the Corresponding Performance Description, Task Metaphor and Performance Metaphor

Freehand Gesture	**Gesture Category**	**Description**	**Task Metaphor** (“as though you are...”)	**Performance Metaphor** (“looks like...”)
Close	A	Both hands start palms face up and move in an arc inwards	Closing a book	Showing the back of your hands to someone
Drop	A	Make a fist and open the fist whilst moving downwards	Letting go of an object	Opening a clenched fist
Move	A	Palm facing down with index finger and middle finger touching the thumb move hand from left to right	Pushing something from here to there	Drawing a line
Open	A	Both hands start palms facing down and move in an arc outwards	Opening a book	Showing you have nothing in your hands
Pick Up	A	Make a grasping movement with palm face down and moving upwards	Pulling an object up	Squeezing a ball
Select	A	Point with the index finger of the right hand	Pointing at an object	A gun
Stop	A	Hold hand up with palm facing front	Halt sign	Push something away from in front you
Move Back	B	With the right hand, palm facing left, move hand from right to left	Scrolling backwards along a line of text	Sliding a lever from right to left
Move Forward	B	With the left hand, palm facing right, move hand from left to right	Scrolling forwards along a line of text	Sliding a lever from left to right
Zoom In	B	Hands apart with palms facing each other, move hands downward and inwards towards a point	Tunnelling in to view	Drawing the letter V going down

Continued on next page

Table 4.1 – *Continued from previous page*

Freehand Gesture	**Gesture Category**	**Description**	**Task Metaphor** (“as though you are...”)	**Performance Metaphor** (“looks like...”)
Zoom Out	B	With palms facing each other, move hands upwards and outwards	Widening view	Drawing the letter V going up
Delete	C	Index finger of the right hand draws a cross	X’ing a window in Microsoft Windows	Drawing the letter X
Go To	C	With the palm facing front move the hand from left to right	Pushing open a door	Waving goodbye
Play	C	With the index finger draw a circle clockwise	Spinning an LP to get it started	Drawing the letter O
Search	C	With the index finger draw a circle anti-clockwise with a tail at the end	Magnifying glass	Drawing the letter Q
Show Me	C	With both hand in front and with palms face up, move the hands away from each other	Shrugging	Holding plates in each hand a passing them to a person on either side of you
Turn On	C	Extend the thumb, index and middle finger and rotate wrist to the right	Turning a radio dial clockwise	Rotating your wrist to the right
Turn Off	C	Extend the thumb, index and middle finger and rotate wrist to the left	Turning a radio dial anti-clockwise	Rotating your wrist to the left

4.2 Method

4.2.1 Design

A two factor mixed experimental design was followed. The independent measure was the metaphor presented to the participants and the repeated measures was the Gesture Category.

The independent measure independent variable was the explanation of the metaphor during training, with three levels (*task metaphor, performance metaphor* or *no metaphor* given). The repeated measures independent variable was the Gesture Category of the freehand gesture (as proposed in Chapter 3), again with three levels (A, B and C) which predict ease of learning based on observed differences in suitability during freehand gesture generation.

Our primary dependent variable was errors in learning. Errors in learning is assessed as the number of errors in 1. retention and 2. accuracy of performance. An error in retention was recorded if the participant forgot or performed the wrong freehand gesture therefore requiring them to be retrained. Incorrect performance was assessed as the freehand gesture not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training - see below for further information.

The second dependent variable was the fit between the freehand gesture and the task, as perceived by the participants (i.e. the suitability of the freehand gesture for the given interaction task). This was measured by the participants rating on a scale of 1..10 (where 1 is not well matched and 10 is very well matched) in response to the question, *"how well the shape and movement of the gesture fitted the interaction task"*.

Finally, data was collected regarding participant familiarity with the freehand gestures as well as how they remembered the freehand gestures. Participants were asked to rate their familiarity with each freehand gesture on a scale of 1..10 (where 1 is not familiar and 10 very familiar) - that is, prior to entering the study had the participant encountered or used this freehand gesture before. All participants were asked to give details of this familiarity.

Participants were also asked to report how they remembered the freehand gesture. For participants in the no metaphor condition this data was collected throughout the study. For participants in the task metaphor and performance metaphor condition this was collected at the end of the study.

4.2.2 Errors in Retention and Accuracy of Performance

Similar to the follow up ease of learning study reported in Chapter 3, in the study reported below no props or interfaces are presented to participants during the study so as to allow participants to solely focus on learning and performing the freehand gestures. Furthermore, rather than implementing a recognition system for this freehand gesture set, the experimenter will assess the accuracy in retention and performance of the freehand gestures performed by participants. The advantage to this approach is that we remove the gulf of execution between, the freehand gestures generated from Chapter 3 which focus on user preferences for freehand gestures and what can be accurately and reliably recognised by a given recognition system.

An error in retention is recorded if the participant forgets or performs the wrong freehand gesture. An error in performance is recorded if the experimenter judges that the freehand gesture performed by the participant does not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training. One challenge for the experimenter is assessing the accuracy of performance. Unlike errors in retention, the experimenter has to make a judgement as to whether the freehand gesture performed by the participant meets the standard of performance as defined prior to the study.

Furthermore, the experimenter has to provide the participant with immediate and consistent feedback regarding the accuracy of performance of the freehand gesture. The study presented is similar to Wizard-of-Oz studies (e.g. Salber and Coutaz [1993]; Dahlback et al. [1993]; Freeman et al. [2012]; Connell et al. [2013]; Lee et al. [2013]) where human operators take the place of recognition systems to trigger actions performed by the user. The advantage to Wizard-of-Oz studies are that they allow developers to simulate a new system or interaction technique to explore design decisions or elicit "natural" interactions (e.g. gestural, speech or multi-modal interactions) from potential end users.

However, one often cited disadvantage to Wizard-of-Oz studies is that often only one wizard is used to trigger actions (e.g. Salber and Coutaz [1993]). In particular the literature highlights that both the wizard and user often adapt to each other. This can be problematic when the wizard anticipates or interprets an action as being performed when it has not been adequately performed by the user. Similarly, the user may adapt their interactions to assist the wizard. For example, the participant might perform interactions with more elaborate or exaggerated movements rather than perform these interactions as if they were interacting "naturally" with a given device or application.

One suggested solution to this challenge is to have multiple wizards. The advantage of multiple wizards is that actions are triggered based on consensus that an interaction has been performed, and performed correctly, by the participant. However, one limitation to multiple wizards is the time delay for wizards to agree if an interaction has been performed. This can often reduce the realism of the simulated system. Similarly, multiple wizard Wizard-of-Oz studies require a highly operationalised set of procedures, including conflict resolution procedures, to efficiently and efficiently recognise interactions and trigger actions.

In the study presented in this chapter, we rely on one experimenter to assess the accuracy of performance of freehand gestures performed by participants. The study was conducted at two locations, the University of Bath and University of Glasgow, with different experimenters at both locations. To assess the accuracy of performance both experimenters were extensively trained on the freehand gestures used in the study. Accuracy of performance is assessed based on the four criteria presented above and shown in the flow chart in Figure 4-1. From this flow chart we can see that there are a number of commonalities between the performance of freehand gestures (e.g. number of fingers used or orientation of the palms) which helps to reduce the complexity of the judgements made by the experimenter. Although, it might be ideal to use multiple experimenters to agree on the accuracy of performance of the freehand gesture performed by participants, this was not possible due to resource limitations.

However, to help ensure that accuracy of performance can be consistently assessed by different experimenters, we examined the errors in performance recorded by the two experimenters for each freehand gesture. A mixed ANOVA was conducted with two independent variables (Experimenter and Freehand Gesture) and one dependent variable (recorded errors in performance) for each session of the study. The results report no signifiant difference between the number of errors in performance recorded by the two experimenters for each freehand gesture across each session of the study - Session 2 (F=0.910, p=0.563), Session 3 (F=0.720, p=0.628), Session 4 (F=0.673, p=0.828) and Session 5 (F=0.353, p=0.993). This suggests that accuracy of performance can, and in this study is, consistently assessed between experimenters.

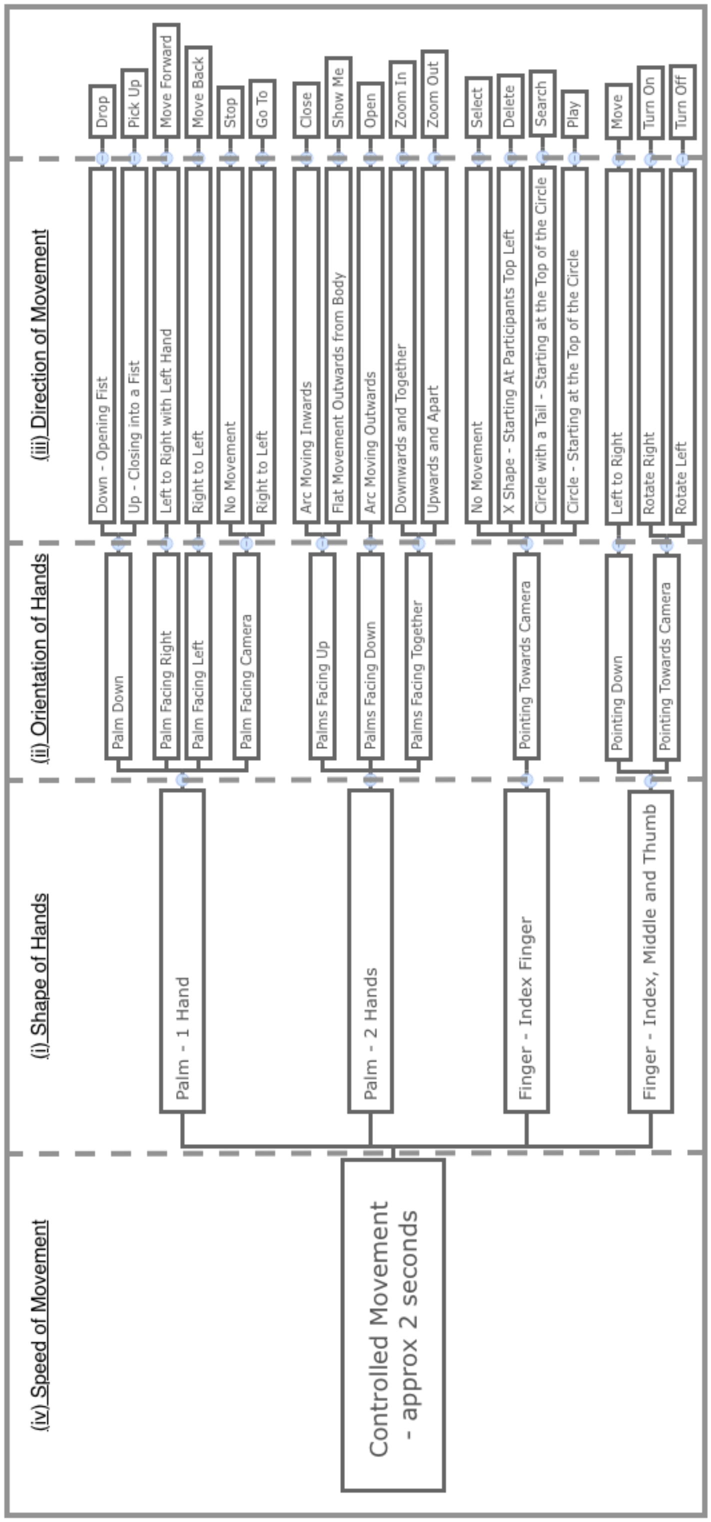


Figure 4-1: Flow Chart of the Criteria for Assessing the Accuracy of Performance of Freehand Gestures

4.2.3 Hypotheses

Metaphor and Learning

Building on the literature which suggests that supporting both mechanisms of transfer of learning has a positive effect on learning, we hypothesis that the use of metaphor, introduced during participant training, will support participants in learning freehand gestures,

H1: The use of metaphor in training will improve participants' learning of freehand gestures

Furthermore, we propose two types of metaphor (i) a *task metaphor* which explains the freehand gesture in terms of an example user task or (ii) a *performance metaphor* which describes the physical shape and movement of the freehand gesture. To better understand which type of metaphor better supports the learning of freehand gestures we hypothesised that,

H2: There will be a difference between the effects of task metaphors and performance metaphors on participants learning of freehand gestures

4.2.4 Participants

Eighteen participants took part in the study, aged from 23 to 38 with a mean age of 30. 11 participants were male and 7 were female. All participants were right-handed. All participants were recruited from around the University of Bath (12 participants) and the University of Glasgow (6 participants). Participants were remunerated £30 for their time.

4.2.5 Procedure

Participants were run individually and randomly allocated to the metaphor experimental condition - *task metaphor, performance metaphor* or *no metaphor* given. The study had two phases, Immediate Learning Phase and Delayed Learning Phase, consisting of five sessions in total; one training session and four learning assessment sessions.

In the Immediate Learning Phase, the participants were trained on the freehand gesture set from Chapter 3 (session 1). Immediately after training, the participants learning of the freehand gestures was assessed (session 2).

The Delayed Learning Phase was administered 7 days (session 3), 14 days (session 4) and 21 days (session 5) after the Immediate Learning Phase. Participants learning of the freehand gestures was again assessed. During the intervening periods, participants received no further training or exposure to the freehand gesture set or metaphors. All of the materials used in this study can be found in Appendix B.1.

Immediate Learning Phase : Session 1 : Training

Participants were trained on the freehand gesture set in Table 4.1. Each participant watched (and listened to) a scripted video. For participants randomly allocated to the *task metaphor* or *performance metaphor* condition, the video first presented the corresponding metaphor for the freehand gesture (see Table 4.1). In all conditions, the video presented the same, name of the freehand gesture corresponding to its interaction task (e.g. *Open, Select, Show Me*), verbal description of how to perform the freehand gesture followed by a demonstration. The presentation order of the freehand gestures was randomised.

After watching the video for each freehand gesture, the participant was asked to perform that freehand gesture correctly 10 consecutive times to the experimenter. If an error was made, it was recorded; the participant was shown the scripted video again and asked to perform the freehand gesture correctly 10 consecutive times. This procedure was repeated until the participant correctly performed the freehand gesture 10 consecutive times.

An error was recorded if the experimenter assessed that the performance of the freehand gesture was not the same as demonstrated in the scripted videos. That is, not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement.

Finally, all participants were given a questionnaire asking them to 1. rate their familiarity with each freehand gesture, 2. give details of this familiarity and 3. rate the fit between the freehand gesture and the task.

Immediate Learning Phase : Session 2 : Learning Assessment

After completing training, the participants immediately participated in a learning assessment task. Participants were run individually and asked to perform the freehand gestures on which they had been trained. The experimenter read aloud the name of a freehand gesture and the participant performed the freehand gesture. The order of the freehand gestures was randomised for each participant and was not the same as the order in which they had just been trained.

If the participant forgot the freehand gesture or performed the freehand gesture incorrectly, the scripted video presenting the metaphor (if one was provided) was played. If the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the scripted video presenting the freehand gesture was played. Finally, if the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the scripted video presenting the demonstration of the freehand gesture being performed was played. At each stage, if the participant performed the freehand gesture correctly the experimenter moved on to the next freehand gesture. All errors were recorded.

Finally, all participants were given a questionnaire asking them to rate how well they thought each freehand gesture fitted the interaction task. Participants in the no metaphor condition were also asked to report how they remembered the freehand gesture.

Delayed Learning Phase : Sessions 3, 4 and 5 : Learning Assessment

Participants returned after 7, 14 and 21 days to participate in a delayed learning phase of the study. During each intervening period no further training on the metaphors or freehand gestures was given. In the delayed learning sessions participants were given the same *Learning Assessment* as described above with the exception of the questionnaire administered.

All participants were given a questionnaire asking them to rate how well they thought each freehand gesture fitted the interaction task. Participants in the *no metaphor* condition were, in addition, asked to report how they remembered the freehand gesture. Participants in the *task metaphor* and *performance metaphor* conditions were asked to report how they remembered the freehand gesture only at the end of session 5.

4.3 Results

The results reported in this section examine the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the learning of freehand gestures. We examine the effect of metaphor, introduced during participant training, on the of learning of freehand gesture (H1). We also examine which type of metaphor better supports the learning of freehand gestures (H2). Finally, we report the results examining how participants in the study (i) rate and report their prior familiarity with the freehand gestures and (ii) report remembering the freehand gestures.

To address H1, we examine the effect of metaphor on, the number of errors in retention and performance as well as participant rating of the suitability of the freehand gestures. Furthermore, we examine the effect across all freehand gestures i.e. the effect on this freehand gesture set as well as on the Gesture Categories i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability (high, medium and low respectively).

4.3.1 Effect of Metaphor on the Number of Errors in Learning

The results reported in this section address whether metaphor, introduced during participant training, supports participant learning of freehand gestures (H1). This section examines whether participants in the *task metaphor* and *performance metaphor* conditions make fewer errors in learning (either in retention or performance) compared to participants in the *no metaphor* condition (H2). First we examine the effect of metaphor on the errors in learning across all freehand gestures. Next we examine the effect of metaphor on the errors in learning across the Gesture Categories

The Effect of Metaphor on the Number of Errors in Learning Across All Freehand Gestures

Initial Learning: Session 2: Examining the errors in retention, a one-way ANOVA test reports that there was a statistically significant difference in the number of errors in retention between metaphor conditions (F=4.704, p=0.01). Post hoc Tukey tests indicate that participants in the *no metaphor* condition made significantly more errors in retention than participants in the *task metaphor* (p=0.013) and *performance metaphor* (p=0.044) condition. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions (p=0.896).

Examining the errors in performance, a one-way ANOVA test reports that there was a statistically significant difference in the number of errors in performance between metaphor conditions (F=10.152, p$<$0.001). Post hoc Tukey tests indicate that participants in the *no metaphor* condition made significantly more errors in performance than participants in the *task metaphor* (p$<$0.001) and *performance metaphor* (p$<$0.001) conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions (p=0.994).

Delayed Learning: Sessions 2 to 5: Examining the errors in retention, a two-way mixed ANOVA indicates a main effect of metaphor condition (F=5.000, p=0.007). Post hoc Tukey tests indicate that participants in the *no metaphor* condition made significantly more errors in retention than participants in the *task metaphor* (p=0.030) and *performance metaphor* (p=0.011) conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions (p=0.938).

There was a main effect of session (F=41.925, p$<$0.001) with contrasts revealing that, for all participants, the errors in retention decreased from session 2 through to session 5. There was also an interaction effect between session and metaphor condition (F=7.125, p$<$0.001) with participants in the *task metaphor* and *performance metaphor* conditions making significantly fewer errors in retention from session 2 through to session 5 compared to participants in the *no metaphor* condition.

Examining the errors in performance, a two-way mixed ANOVA indicates a main effect of metaphor condition (F=11.919, p$<$0.001). Post hoc Tukey tests indicate that participants in the *no metaphor* condition made significantly more errors in performance than participants in the *task metaphor* (p$<$0.001) and *performance metaphor* (p$<$0.001) conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions (p=0.997).

There was a main effect of session (F=23.915, p<0.001) with contrasts revealing that for all participants, the errors in performance decreased from session 2 through to session 5. There was also an interaction effect between session and metaphor condition (F=7.011, p<0.001) with participants in the *task metaphor* and *performance metaphor* conditions making significantly fewer errors in performance from session 2 through to session 5 compared to participants in the *no metaphor* condition.

The Effect of Metaphor on the Number of Errors in Learning Across Gestures Categories

Initial Learning: Session 2: We conducted a two-way mixed ANOVA, with one repeated measure (Gesture Category) and one independent measure (metaphor condition). Examining the errors in retention, the results indicate no main effect of metaphor condition (F=0.662, p=0.530). However, there was a main effect of Gesture Category (F=4.541, p=0.047) with contrasts revealing that all participant made fewer errors in retention for freehand gestures in Category C compared to freehand gestures in Category A (F=12.987, p=0.003) and freehand gestures in Category B (F=5.284, p=0.036). Freehand gestures in Category A produced similar numbers of errors in retention as freehand gestures in Category B (F=2.750, p=0.118).

Examining the errors in performance, a two-way mixed ANOVA reports that there is no main effect of metaphor condition (F=2.279, p=0.137). However, there was a main effect of Gesture Category (F=12.751, p=0.003) with contrasts revealing that all participant made more errors in performance for freehand gestures in Category B compared to freehand gestures in Category A (F=12.556, p=0.003) and freehand gestures in Category C (F=13.178, p=0.002). Freehand gestures in Category A produced similar numbers of errors in performance as freehand gestures in Category B (F=0.0, p=1.0).

Delayed Learning: Sessions 2 to 5: We conducted a three-way mixed ANOVA, with two repeated measures (Gesture Category and session) and one independent measure (metaphor condition). Examining the errors in retention, the results indicate no main effect of metaphor condition (F=1.457, p=0.264). However, there was a main effect of session (F=12.729, p<0.001) with contrasts revealing that for all participants, the errors in retention decreased significantly from session 2 through to session 5.

There was also a main effect of Gesture Category (F=8.256, p=0.010). Contrasts revealed that all participant made more errors in retention for freehand gestures in Category B compared to freehand gestures in Category A (F=6.629, p=0.021) and freehand gestures in Category C (F=9.664, p=0.007). Contrasts also revealed that freehand gestures in Category A produced more errors in retention than freehand gestures in Category C (F=9.758, p=0.007).

There was no interaction effect between session and metaphor condition on the number of errors in retention (F=0.518, p=0.684). There was also no interaction effect between Gesture

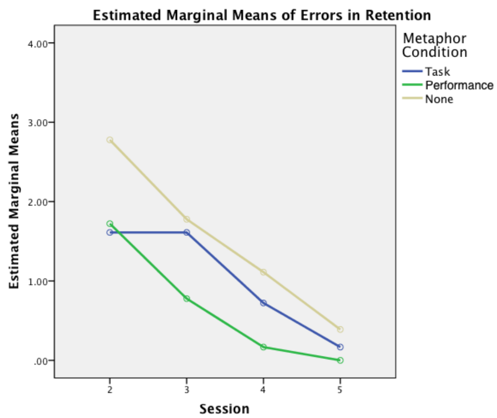
Category and metaphor condition on the number of errors in retention (F=0.995, p=0.396).

Examining the errors in performance, a three-way mixed ANOVA reports a main effect of metaphor condition (F=3.726, p=0.049). Post hoc Tukey tests indicate that participants in the *performance metaphor* condition made significantly less errors in performance than participants in the *no metaphor* condition (p=0.05). There was no such significant difference between participants in the *task metaphor* and *no metaphor* conditions (p=0.104) as well as the *task metaphor* and *performance metaphor* conditions (p=0.924).

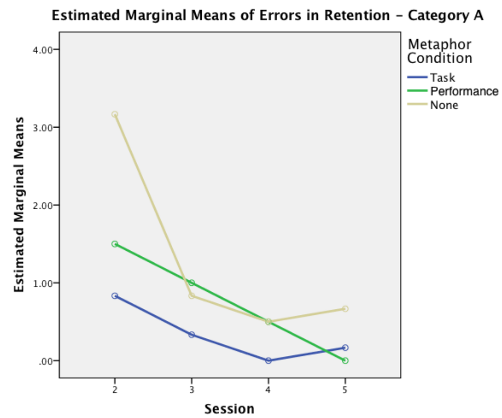
There was a main effect of session (F=19.972, p$<$0.001) with contrasts revealing that for all participants, the errors in performance decreased from session 2 through to session 5. There was also a main effect of Gesture Category (F=18.971, p$<$0.001) with contrasts revealing that all participant made more errors in performance for freehand gestures in Category B compared to freehand gestures in Category A (F=19.248, p=0.001) and freehand gestures in Category C (F=19.087, p=0.001). Category A freehand gestures produced similar errors in performance as freehand gestures in Category C (F=1.976, p=0.180).

There was no interaction effect between session and metaphor condition on the number of errors in performance (F=1.666, p=0.213). There was also no interaction effect between Gesture Category and metaphor condition on the number of errors in performance (F=1.882, p=0.184).

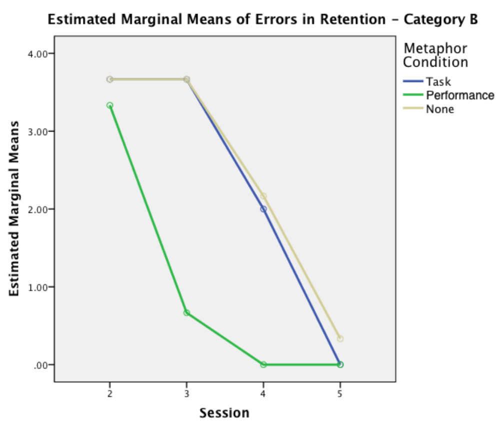
Figure 4-2a shows the errors in retention for each metaphor condition across sessions 2 - 5. Figure 4-2b shows all errors in retention made by participants in each metaphor condition for freehand gestures in Category A, Figure 4-2c for freehand gestures Category B and Figure 4-2d for freehand gestures Category C. Similarly, Figure 4-3a shows the errors in performance for each metaphor condition across sessions 2 - 5, with Figures 4-3b, 4-3c and 4-3d showing errors in performance for each Gesture Category.



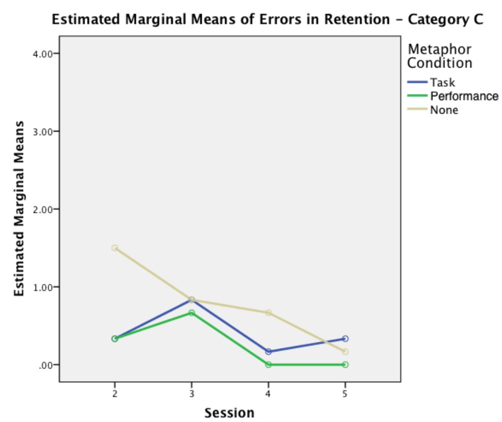
(a) All Errors in Retention



(b) Errors in Retention - Category A

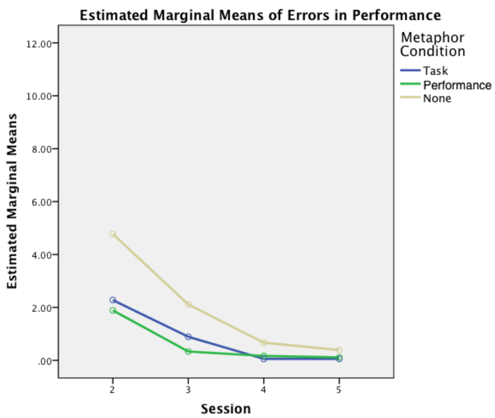


(c) Errors in Retention - Category B

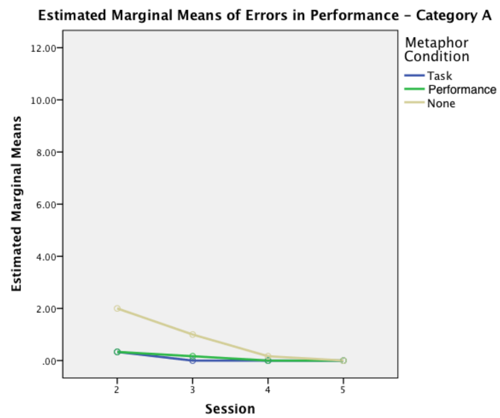


(d) Errors in Retention - Category C

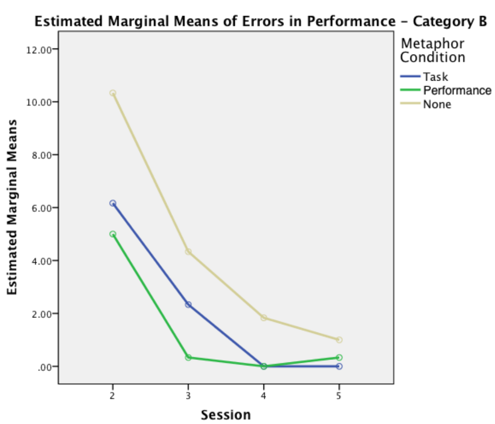
Figure 4-2: Errors in Retention for each Metaphor Condition Across Sessions 2 - 5



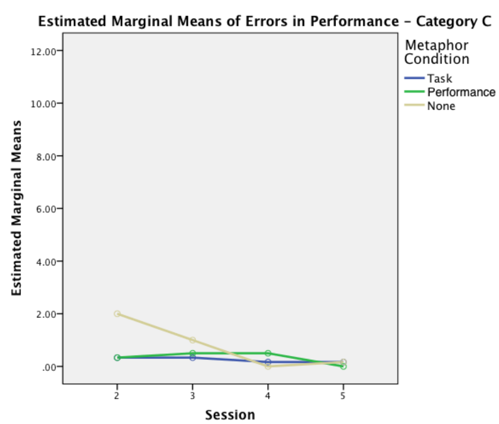
(a) All Errors in Performance



(b) Errors in Performance - Category A



(c) Errors in Performance - Category B



(d) Errors in Performance - Category C

Figure 4-3: Errors in Performance for each Metaphor Condition Across Sessions 2 - 5

4.3.2 Effect of Metaphor on the Suitability of Freehand Gestures

The results reported in this section examine the effect of metaphor, introduced during participant training, on the learning of freehand gestures (H1). Specifically, we examine if metaphor, introduced during participant training, has an effect on the participants perception of the fit between the freehand gesture and the task (i.e. the suitability of the freehand gesture). First we examine the effect of metaphor across all freehand gestures. Next we examine the effect of metaphor on the Gesture Categories.

The Effect of Metaphor on the Perception of Suitability Across All Freehand Gestures

Training: Session 1: A one-way ANOVA test reports that there was a statistically significant difference in participant rating of the fit between the freehand gesture and the task between metaphor conditions ($F=6.684, p=0.001$). Post hoc Tukey tests indicate that participants in the *no metaphor* condition rate the fit between the freehand gesture and the task significantly lower than participants in the *task metaphor* ($p=0.005$) and *performance metaphor* ($p=0.004$) conditions. There was no such significant difference between participants in the task metaphor and performance metaphor conditions ($p=0.998$).

Initial Learning: Session 2: A one-way ANOVA test reports that there was a statistically significant difference in participant rating of the fit between the freehand gesture and the task between metaphor conditions ($F=11.688$, $p<0.001$). Post hoc Tukey tests indicate that participants in the *no metaphor* condition rate the fit between the freehand gesture and the task significantly lower than participants in the *task metaphor* ($p<0.001$) and *performance metaphor* ($p<0.001$) conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions ($p=0.999$).

Delayed Learning: Sessions 2 - 5: A two-way mixed ANOVA was conducted, with one repeated measure (session) and one independent measure (metaphor condition). The results indicate a main effect of metaphor condition ($F=14.444$, $p<0.001$). Post hoc Tukey tests indicate that participants in the *no metaphor* condition rate the fit between the freehand gesture and the task significantly lower than participants in the *task metaphor* ($p<0.001$) and *performance metaphor* ($p<0.001$) conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions ($p=0.646$).

Furthermore, the results indicate a main effect of session ($F=6.912$, $p<0.001$) with contrast revealing that there was a significant increase in the rating of the fit between the freehand gesture and the task between session 3 and session 4 ($F=17.516$, $p<0.001$).

The results also report an interaction effect between session and metaphor condition ($F=5.463$,

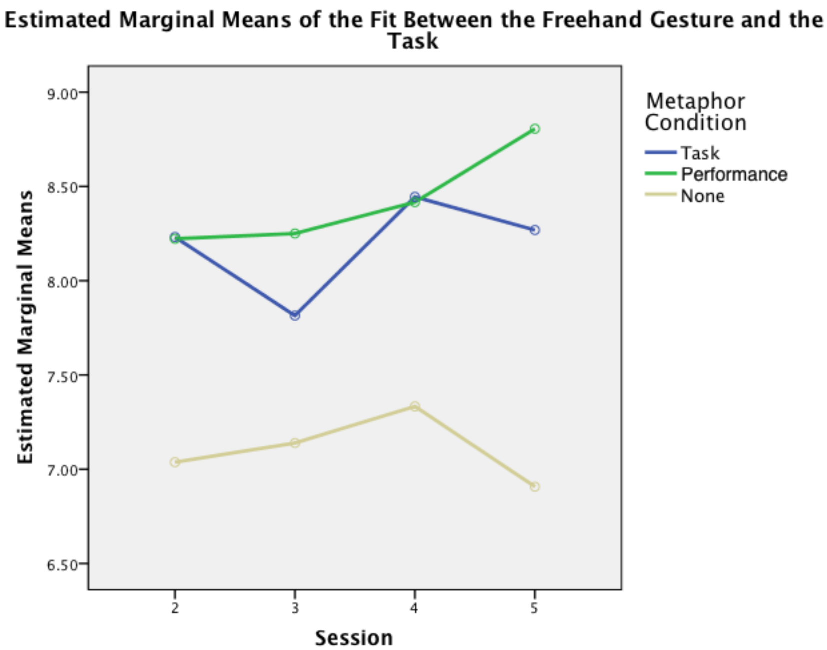


Figure 4-4: Rating of the Fit Between the Freehand Gesture and the Task for Across All Freehand Gestures for each Metaphor Condition

p<0.001) with contrasts revealing that participants in each metaphor condition rated the fit between the freehand gesture and the task significantly differently between session 2 and session 3 (p=0.008) and session 4 and session 5 (p<0.001) (see Figure 4-4). Examining the means showed that between session 2 and session 3 the rating of the fit between the freehand gesture and the task increased across all metaphor conditions however, for participants in the *task metaphor* condition the increase is notably larger (from 7.82 (*sd*=0.23) in session 2 to 8.44 (*sd*=0.20) in session 3). Between session 4 and 5 the rating of the fit between the freehand gesture and the task decreased for participants in the *no metaphor* and *task metaphor* conditions but increased for participants in the *performance metaphor* condition.

The Effect of Metaphor on the Perception of Suitability Across Gestures Categories

Training: Session 1: A two-way mixed ANOVA was conducted, with one repeated measures (Gesture Category) and one independent measure (metaphor condition). The results indicate a main effect of Gesture Category (F=25.370, p<0.001). Contrasts reveal that all participant rate freehand gestures in Category A higher than Category B (F=19.180, p=0.001) and Category C (F=50.542, p<0.001). Similarly, freehand gestures in Category B are rated higher than freehand gestures in Category C (F=4.532, p=0.05).

However, there was no main effect of metaphor condition on participant rating of the fit between the freehand gesture and the task ($F=2.317$, $p=0.133$).

Initial Learning: Session 2: A two-way mixed ANOVA was conducted, with one repeated measures (Gesture Category) and one independent measure (metaphor condition). The results indicate a main effect of Gesture Category ($F=19.503$, $p<0.001$). Contrasts reveal that all participant rate freehand gestures in Category A higher than Category B ($F=20.686$, $p<0.001$) and Category C ($F=52.580$, $p<0.001$). However, freehand gestures in Category B were not rated significantly differently from freehand gestures in Category C ($F=0.078$, $p=0.784$).

Furthermore, the results indicate a main effect of metaphor condition ($F=4.076$, $p=0.039$). Post hoc Tukey tests indicate that participants in the *performance metaphor* condition rate the fit between the freehand gesture and the task significantly higher than participants in the *no metaphor* condition ($p=0.05$). There is no such difference between participants in the *task metaphor* and *no metaphor* conditions ($p=0.076$) or between participants in the *performance metaphor* and *task metaphor* conditions ($p=0.981$).

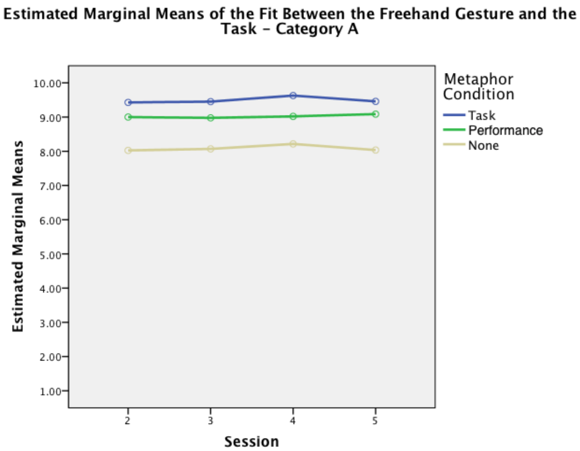
There was no interaction effect between Gesture Category and metaphor condition ($F=1.585$, $p=0.220$).

Delayed Learning: Sessions 2 - 5: A three-way mixed ANOVA was conducted, with two repeated measures (Gesture Category and session) and one independent measure (metaphor condition). The results indicating a main effect of Gesture Category ($F=24.835$, $p<0.001$). Contrasts reveal that all participants rate freehand gestures in Category A higher than Category B ($F=30.059$, $p<0.001$) and Category C ($F=42.016$, $p<0.001$). However, freehand gestures in Category B were not rated significantly differently from freehand gestures in Category C ($F=0.358$, $p=0.558$).

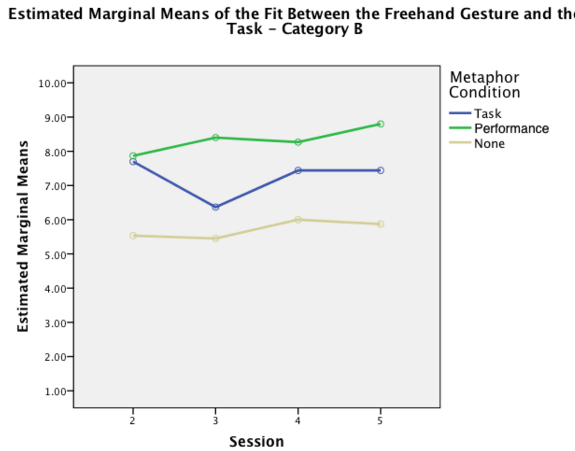
Furthermore, the results indicate a main effect of metaphor condition ($F=5.536$, $p=0.016$). Post hoc Tukey tests indicate that participants in the *performance metaphor* condition rate the fit between the freehand gesture and the task significantly higher than participants in the *no metaphor* condition ($p=0.015$). There is no such difference between participants in the *task metaphor* and *no metaphor* conditions ($p=0.077$) or between participants in the *performance metaphor* and *task metaphor* conditions ($p=0.685$).

There was no main effect of session ($F=1.929$, $p=0.165$). There was also no interaction effects between Gesture Category and metaphor condition ($F=2.509$, $p=0.063$), Gesture Category and session ($F=1.450$, $p=0.230$) or session and metaphor condition ($F=0.849$, $p=0.508$).

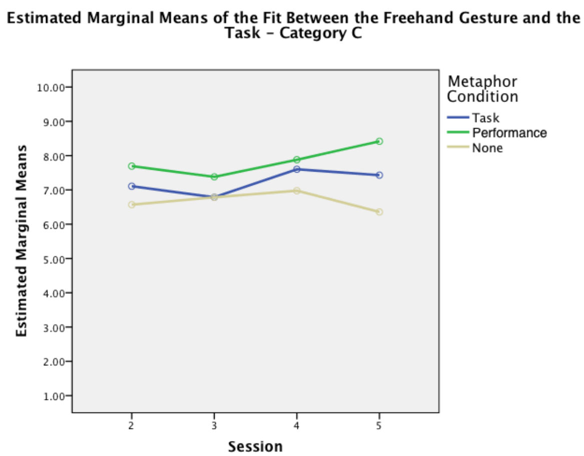
Figure 4-5 shows the means of the ratings of the fit between the freehand gesture and the task for each Gesture Category made by participants in each of the three metaphor conditions.



(a) Category A



(b) Category B



(c) Category C

Figure 4-5: Rating of the Fit Between the Freehand Gesture and the Task for each Gesture Category for each Metaphor Condition

4.3.3 Participant Rating and Self Reporting of their Prior Familiarity with the Freehand Gestures

This section reports the results of participant rating and self reporting of prior familiarity with the freehand gestures.

A two-way mixed ANOVA was conducted, with one repeated measures (Gesture Category) and one independent measure (metaphor condition). The results indicate no main effect of metaphor condition on participant rating of familiarity ($F=0.714$, $p=0.506$). However, there was a main effect of Gesture Category ($F=17.035$, $p<0.001$), with contrasts revealing that participants rated familiarity significantly differently for each Gesture Category. Freehand gestures in Category A were rated a most familiar and freehand gestures in Category B the least familiar.

Figure 4-6 shows the mean ratings of familiarity for each freehand gesture for all participants. Figure 4-6 shows that freehand gestures in Category A are all rated as very familiar whereas freehand gestures in Category B are all rated as being unfamiliar. Freehand gestures in Category C however, are a mix of familiar (i.e. *Delete, Turn On* and *Turn Off*) and unfamiliar (i.e. *Play, Go To, Search* and *Show Me*) freehand gestures.

Additionally, participants were asked to report from where they were familiar with the freehand gesture. Table 4.2 shows the responses made by participants who completed this question.

From Table 4.2 we can see that participants provide a wide range of prior experiences from which they are familiar with the freehand gestures. For example, the *Turn On* freehand gesture was reported as familiar from "turning on a radio" and "like some physical switches", the *Move Back* freehand gesture was reported as familiar from "pushing through a crowd" and the *Zoom In* freehand gesture was reported as familiar from "asking for assistance".

Interestingly, some participants reported their familiarity with a freehand gesture from it being "natural" or "commonly used in everyday life". It is also interesting to note that for the *Delete* freehand gesture participants reported their familiarity was from "Windows OS", "cross on a window on a computer" and "computer".

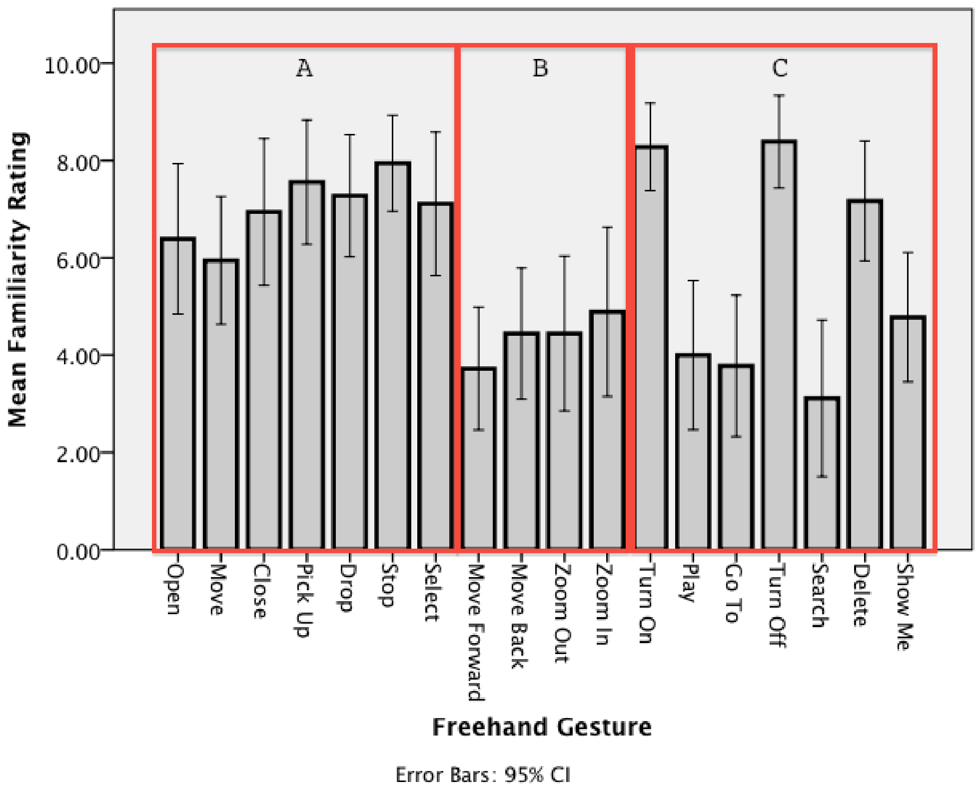


Figure 4-6: Mean Ratings of Participant Familiarity with Each of the Freehand Gestures

Table 4.2: Participant Rating of their Familiarity with the Freehand Gestures and From Where they are Familiar with the Freehand Gestures.

Freehand Gesture	**Gesture Category**	**Participant**	**Metaphor Condition**	**Familiarity**	**From Where?**
Close	A	P1	Task	10	Closing a book
		P4	Task	9	Book
		P7	Task	10	Closing a window
		P10	Task	9	A gesture that I've used myself
		P8	Gesture	10	Closing a book
		P11	Gesture	8	Closing a book
		G5	Gesture	8	Opposite to open
		P3	None	10	Nature of gesture
		P9	None	7	Like closing a book
		G1	None	5	Closing a door, box
Drop	A	P1	Task	6	When I drop stuff
		P4	Task	9	Natural movement
		P10	Task	9	Again a familiar gesture
		P8	Gesture	10	Like dropping something
		P11	Gesture	7	Putting down
		G5	Gesture	8	Dropping a ball
		P3	None	10	Life
		P9	None	7	Like physical movement
		G1	None	8	Dropping something on the floor
Move	A	P1	Task	7	When I move small stuff
		P7	Task	10	Move stuff from a desk
		P10	Task	3	When picking something up on a table to move
		G2	Task	6	Kind of gesture you would use in conversation. Also when actually picking stuff up
		P5	Gesture	7	During driving, letting other cars pass
		P8	Gesture	6	Picking something up and moving it from A to B
		P11	Gesture	7	Zipping a bag
		G5	Gesture	9	Drawing a line
		P9	None	8	Like physical movement

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Table 4.2 – *Continued from previous page*

Freehand Gesture	**Gesture Category**	**Participant**	**Metaphor Condition**	**Familiarity**	**From Where?**
Open	A	P1	Task	10	Open a book
		P4	Task	9	Book
		P7	Task	9	Book
		P10	Task	9	Hands starting close together then outwards
		G4	Task	10	Remembering a book
		P8	Gesture	8	Opening a book
		P11	Gesture	8	Opening a book
		G5	Gesture	8	Open in sign language
		P3	None	5	Nature of the gesture
		P9	None	7	Like opening a book
		G1	None	8	Opening a parcel, box, present
Pick Up	A	P1	Task	10	When I pick stuff
		P4	Task Up	9	Natural movement
		P10	Task	9	A mimic of an actual movement ”to pick up”
		G2	Task	4	Not as a gesture but action e.g., picking up a kitten by the scruff of the neck
		P8	Gesture	10	Like picking something up
		P11	Gesture	7	Picking up
		G5	Gesture	8	Picking something up
		P3	None	10	Life
		P9	None	7	Like physical movement
		G1	None	8	Picking up a stone
Select	A	P4	Task	8	iPad
		P10	Task	10	I’ve used this gesture when addressing people
		G2	Task	10	Pointing at things or people (rude!)
		P11	Gesture	6	Giving directions
		G5	Gesture	10	Pointing
		P9	None	8	Commonly used gesture for selecting
		G1	None	7	Pointing at something interesting
Stop	A	P1	Task	10	Common gesture

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Table 4.2 – *Continued from previous page*

Freehand Gesture	**Gesture Category**	**Participant**	**Metaphor Condition**	**Familiarity**	**From Where?**
		P4	Task	9	Traffic warden
		P7	Task	10	Used in body language to stop someone
		P10	Task	10	A police signal when on the road
		G2	Task	10	Traffic wardens, police etc.
		P5	Gesture	8	During chats with friends, family etc.
		P8	Gesture	10	Police stop gesture
		P11	Gesture	9	Films, TV, even the Spice Girls
		G5	Gesture	9	Traffic warden, stop sign
		P9	None	8	Commonly used gesture for stop
		G6	None	7	Traffic sign
Move Back	B	P11	Gesture	6	Pushing through a crowd
		G5	Gesture	8	Pushing something along
Move Forward	B	P11	Gesture	6	Door opening/closing
		G6	None	4	Television
Zoom In	B	P10	Task	9	Familiar when asking for assistance
		G5	Gesture	9	Drawing a V
		P3	None	10	Nature of gesture
Zoom Out	B	G5	Gesture	8	Opposite to Zoom In
		P3	None	10	Nature of gesture
Delete	10	P1	Task	C	When I write and I want to cross something out
		P4	Task	7	Cultural and Windows
		P7	Task	10	Windows OS
		P10	Task	10	Is a common expression used in literature
		G4	Task	10	Simple cross
		P5	Gesture	7	In the office or house
		P8	Gesture	10	Cross on a window on a computer
		G5	Gesture	10	Writing the letter X
		P3	None	5	Computers
		P9	None	8	Shape of a common delete icon
Go To	C	G5	Gesture	8	Wave goodbye

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Table 4.2 – *Continued from previous page*

Freehand Gesture	**Gesture Category**	**Participant**	**Metaphor Condition**	**Familiarity**	**From Where?**
Play	C	P11	Gesture	6	Sparklers of November 5th
		G5	Gesture	8	Drawing a circle
Search	C	G5	Gesture	9	Drawing a Q or 9
		G1	None	3	Writing the letter Q
Show Me	C	P10	Task	8	Used when I'm not certain about something
		P11	Gesture	6	Shrugging shoulders
		G5	Gesture	9	Begging for something
		P9	None	6	Commonly used gesture for ”don't know”
Turn On	C	P1	Task	8	Turn volume of a physical device like radio with knobs
		P4	Task	9	Electrical equipment/volume
		P7	Task	10	Radio
		P10	Task	10	Turning on a radio switch
		G2	Task	10	Indicate to someone to turn up volume on radio
		G4	Task	10	Knob switch
		P5	Gesture	9	In the house when someone is busy
		P8	Gesture	10	Using everyday object
		P11	Gesture	8	Radio and various control dials
		G5	Gesture	9	Turning a knob, car radio
		P3	None	10	Life
		P9	None	8	Like some physical switches
		G1	None	8	Car keys, engine
Turn Off	C	P1	Task	10	Turn volume of video down
		P4	Task	9	Electrical equipment/volume
		P7	Task	10	Radio device
		P10	Task	10	When switching something off
		G2	Task	10	Indicate to someone to turn up volume on radio
		P5	Gesture	9	When music is too loud and you want other person to turn it off
		P8	Gesture	10	Using everyday object
		P11	Gesture	8	Radio and various control dials

Continued on next page

Table 4.2 – *Continued from previous page*

Freehand Gesture	**Gesture Category**	**Participant**	**Metaphor Condition**	**Familiarity**	**From Where?**
		G5	Gesture	9	Opposite to Turn On
		P3	None	10	Life
		P9	None	8	Like some physical switches
		G6	None	4	Car keys, engine

4.3.4 Participant Self Reporting of How They Remembered Freehand Gestures

This section reports the results of participant self reporting of how they remembered the freehand gestures. Participants in the *task metaphor* and *performance metaphor* conditions were asked to report how they remembered each of the freehand gestures after completing the final *Delayed Learning Assessment* (session 5). Participants in the *no metaphor* were asked to report how they remembered each of the freehand gestures after completing each session 2 - 5.

Table 4.3 shows how participants in the *task metaphor* and *performance metaphor* conditions reported how they remembered each of the freehand gestures. From Table 4.3 we can see that participants report a wide range of different metaphors used to remember the freehand gestures. Participants reported metaphors such as “close tap” for the freehand gesture *Turn Off*, “pig tail” for *Search* and “cone down” for *Zoom In*. From these different participant reported metaphors, it is interesting to note that the majority are not the metaphors presented to participants during training.

Furthermore, the reported metaphors, are both task like metaphors and performance like metaphor. For freehand gestures in Category A as well as the freehand gesture *Turn On* and *Turn Off* the reported metaphors are by majority task like metaphors e.g. “open backgammon set”, “stopping traffic” and “turning on a radio”. In contrast freehand gestures in Category B and C are by majority performance like metaphors e.g. “going from left to right”, “cone up”, “letter X” and “clockwise circle”.

Table 4.4 shows how participants in the *no metaphor* condition reported how they remembered each of the freehand gestures. From Table 4.4 we can see that compared to participants in the *task metaphor* and *performance metaphor* conditions, participants in the *no metaphor* condition report less rich metaphors by which they remember the freehand gestures. Participants in the *no metaphor* condition often report that they remembered the freehand gesture from “life experience” or because it “makes sense” or “by repetition”. Interestingly one participant remembered certain freehand gestures by comparison to another freehand gesture e.g. the participant reported that they remembered the freehand gesture *Open* by “comparing with *Close*” and that they remembered the freehand gesture *Close* by “comparing with *Open*”.

Where a metaphor was provided, participants in the *no metaphor* condition often report a performance like metaphor which interestingly, was regardless of Gesture Category.

Finally, examining the difference in how participants in the *no metaphor* condition reported how they remembered freehand gestures over the four sessions, we can see that often the originally reported metaphor in session 2 is the same when reported in session 5. Where the reported metaphor changes, this is often due to the addition of an important physical feature. For example, for the freehand gesture *Play* one reported metaphor in session 2 was “circle” which changes to “clockwise circle” in session 5 . Similarly, for the freehand gesture *Go To* one reported metaphor in session 2 was “a wave” which changes to “wave palm” in session 5 .

Table 4.3: Self Reporting of How Participants in the *Task Metaphor* and *performance metaphor* Conditions Remembered Each Freehand Gesture.

Freehand Gesture	**Partic-ipant**	**Metaphor Condi-tion**	**How Did you Remember**
Close (A)	P4	Task	Close backgammon
	P7	Task	Close book
	P10	Task	Closing a book after reading
	G2	Task	Think of a big book
	G4	Task	Closing a book
	P2	Gesture	Like close the box
	P5	Gesture	Closing a book
	P11	Gesture	Book closing
	G3	Gesture	-
	G5	Gesture	Showing the back of my palms
Drop (A)	P4	Task	Grab, fist down
	P7	Task	Drop an item from my hand
	P10	Task	This gesture would actually be performed
	G2	Task	I imagine I am letting go of a damp tea towel
	G4	Task	Opposite of Pick Up
	P2	Gesture	Like dropping a bag
	P5	Gesture	Dropping something, opening your fist
	P11	Gesture	Dropping something
	G3	Gesture	-
	G5	Gesture	Dropping something
Move (A)	P4	Task	Orthodox pray style
	P7	Task	Move item from one place to another

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Table 4.3 – *Continued from previous page*

Freehand Gesture	**Partic-ipant**	**Metaphor Condi-tion**	**How Did you Remember**
	P10	Task	Remembered after countless repetition
	G2	Task	Gesture is quite natural
	G4	Task	Taking a thing from one place to another
	P2	Gesture	Like move thing on the table
	P5	Gesture	Like drawing a line
	P11	Gesture	Chess piece move
	G3	Gesture	-
	G5	Gesture	Picking something and then moving it
Open (A)	P4	Task	Open Backgammon set
	P7	Task	Open book
	P10	Task	Opening a book to read
	G2	Task	I think of a big book
	G4	Task	Thought of opening a book
	P2	Gesture	Like open a box
	P5	Gesture	Opening a book
	P11	Gesture	Book opening
	G3	Gesture	-
	G5	Gesture	Showing my palms
Pick Up (A)	P4	Task	Grab, fist up
	P7	Task	Pick up an item
	P10	Task	This gesture would actually be performed
	G2	Task	I imagine I am grabbing a tea towel
	G4	Task	Normal picking up something
	P2	Gesture	Like picking a bag
	P5	Gesture	Picking something from the floor
	P11	Gesture	Picking something up
	G3	Gesture	-
	G5	Gesture	Picking up something
Select (A)	P4	Task	Show and tell
	P7	Task	Pointing at someone
	P10	Task	Just had to remember to think about selecting something
	G2	Task	Natural gesture - I imagine I am pointing at something in a shop
	G4	Task	Only one with fingers in use
	P2	Gesture	Point out

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Table 4.3 – *Continued from previous page*

Freehand Gesture	**Partic-ipant**	**Metaphor Condi-tion**	**How Did you Remember**
	P5	Gesture	Like showing someone with your finger or like shooting
	P11	Gesture	Pointing
	G3	Gesture	-
	G5	Gesture	Pointing
Stop (A)	P4	Task	Halt, military
	P7	Task	When asking someone to stop using hand
	P10	Task	A symbol I have experienced while driving
	G2	Task	Very natural gesture
	G4	Task	Easy to remember, normal gesture
	P2	Gesture	Intuition for stop
	P5	Gesture	Like pushing someone/something
	P11	Gesture	Stopping traffic
	G3	Gesture	-
	G5	Gesture	Stop sign
Move Back (B)	P4	Task	-
	P7	Task	Browser backwards
	P10	Task	-
	G2	Task	From practise
	G4	Task	opposite of Move Forward
	P2	Gesture	Use my right hand (same thing with Move Forward but using the opposite hand)
	P5	Gesture	Going from right to left
	P11	Gesture	Browser back button
	G3	Gesture	-
	G5	Gesture	Moving a .... backwards
Move Forward (B)	P4	Task	-
	P7	Task	Browser forward
	P10	Task	By remembering after trial and error that forward was the key word
	G2	Task	From video and repeating the movement
	G4	Task	Only one with left hand
	P2	Gesture	Use my left hand (only one that uses left hand)
	P5	Gesture	Going from left to right
	P11	Gesture	Browser forward button

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Table 4.3 – *Continued from previous page*

Freehand Gesture	Participant	Metaphor Condition	How Did you Remember
	G3	Gesture	-
	G5	Gesture	Moving a ...
Zoom In (B)	P4	Task	Cone down
	P7	Task	-
	P10	Task	Again remembered it's used in types of media like film
	G2	Task	I move my eyes along with my hands to a smaller area
	G4	Task	Opposite of Zoom Out, other one with two hands
	P2	Gesture	Triangle, top down
	P5	Gesture	Drawing a "V" opposite of zoom out
	P11	Gesture	Cone contracting
	G3	Gesture	-
	G5	Gesture	Drawing a V
Zoom Out (B)	P4	Task	Cone up
	P7	Task	-
	P10	Task	Could relate the gesture to certain media form
	G2	Task	Lifting hands as in prayer
	G4	Task	Both hands coming into play and going up
	P2	Gesture	Triangle, bottom up
	P5	Gesture	Drawing a "V" downwards to upwards
	P11	Gesture	Cone expanding
	G3	Gesture	-
	G5	Gesture	Opposite of a V
Delete (C)	P4	Task	"X"
	P7	Task	Windows "X" sign for closing windows
	P10	Task	Have become well known with this symbol before
	G2	Task	Think of computer X e.g., Buttons on e-mail
	G4	Task	Making a cross in the air
	P2	Gesture	Letter "X"
	P5	Gesture	Like the letter "X"
	P11	Gesture	Cross
	G3	Gesture	-
	G5	Gesture	Drawing an X
Go To (C)	P4	Task	Say hello
	P7	Task	Open door, iPhone go to

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Table 4.3 – *Continued from previous page*

Freehand Gesture	**Partic-ipant**	**Metaphor Condi-tion**	**How Did you Remember**
	P10	Task	Just from repetition
	G2	Task	From practise
	G4	Task	Make the movement bye bye
	P2	Gesture	Gesture that is not a good match with the metaphor
	P5	Gesture	Move item from left to right
	P11	Gesture	Window wipe
	G3	Gesture	-
	G5	Gesture	Waving
Play (C)	P4	Task	DJ for LP disk
	P7	Task	Circle in space looks like play shape in media player
	P10	Task	By comparing it to the iPod symbol for ”play”
	G2	Task	I remember the metaphor
	G4	Task	Circular figure
	P2	Gesture	Draw a circle but start from right to left
	P5	Gesture	Like ”0” number
	P11	Gesture	Clockwise circle
	G3	Gesture	-
	G5	Gesture	Drawing a circle
Search (C)	P4	Task	Pig tail
	P7	Task	Like ”Q”, but opposite direction with extra circle inside
	P10	Task	I felt search and play were related as in iPod
	G2	Task	I draw a kind of letter Q - as in question or query
	G4	Task	A bit tough, but Play helped to remember
	P2	Gesture	Letter ”Q”
	P5	Gesture	Like the letter ”Q”
	P11	Gesture	Anti-clockwise circle with a tail
	G3	Gesture	-
	G5	Gesture	Drawing a Q
Show Me (C)	P4	Task	The Italian
	P7	Task	Body language of show me
	P10	Task	The gesture itself reminded me that I don’t know how to do something
	G2	Task	I imagine I am doing some kind of illegal transaction
	G4	Task	Most weird gesture, that helped me to remember

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Table 4.3 – *Continued from previous page*

Freehand Gesture	**Partic-ipant**	**Metaphor Condi-tion**	**How Did you Remember**
	P2	Gesture	Like the gesture of ”I don’t mind”. ”so what”
	P5	Gesture	like holding something with your hands and open and moving them out of your body
	P11	Gesture	Passing plates
	G3	Gesture	-
	G5	Gesture	Showing my palms
Turn On (C)	P4	Task	Open tap
	P7	Task	Turn on radio
	P10	Task	Practical association mainly
	G2	Task	I think of a big stereo system
	G4	Task	Turning on a knob/switch
	P2	Gesture	Like open the door
	P5	Gesture	Turning on a radio
	P11	Gesture	Analogue dial (radio)
	G3	Gesture	-
	G5	Gesture	Turning a knob
Turn Off (C)	P4	Task	Close tap
	P7	Task	Turn off radio
	P10	Task	Again by doing it practically
	G2	Task	Big stereo system
	G4	Task	Turning off knob/switch
	P2	Gesture	Like closing the lib
	P5	Gesture	Turn off the radio
	P11	Gesture	Analogue dial (radio)
	G3	Gesture	-
	G5	Gesture	Turning a knob

Table 4.4: Self Reporting of How Participants in the *No Metaphor* Condition Remembered each Freehand Gesture Recorded at the end of Sessions 2, 3, 4 and 5.

Freehand Gesture	**Partic-ipant**	**Session 2**	**Session 3**	**Session 4**	**Session 5**
Close (A)	P3	Life	Close a box	Life experience	Life experience
	P6	Closing	Comparing with Open	Comparing with Open	Comparing with Open
	P9	Close a book, but end palms down	Like a book	Like a book, open reversed	Like open, start palms up
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Parcel, box	Package	Package, box close	Close a package
	G6	Fit gesture - easy to remember	Palm close gesture	Palm downward	Palm downward
Drop (A)	P3	Life	Life experience	Life experience	Life experience
	P6	Dropping a bag	Dropping luggage	Dropping luggage	Drop a box
	P9	Drop gesture	Opposite of Pick Up	Like physical movement, opposite of Pick Up	Like physical movement, opposite of Pick Up
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Drop stone	-	Dropping something	-
	G6	Fit gesture - easy to remember	Up down	Up to down movement	Up to down movement
Move (A)	P3	Life	Life experience	Life experience	Life experience
	P6	Like a zip (opening a zip)	Like a luggage zip	Like zip of luggage	Like zip on luggage
	P9	Pick up and move	Pick up and move	Pick up and move an object	Pick up and put down something
	P12	By repetition	Makes sense	Makes sense	Makes sense
	G1	-	-	-	-
	G6	To pick and drop	Taking from one place to another	One place to the next	From one point to another
Open (A)	P3	Life	Like open a box	Life experience	Life experience
	P6	Comparing with Close	Comparing with Close	Comparing with Close	Comparing with Close

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Table 4.4 – *Continued from previous page*

Freehand Gesture	**Participant**	**Session 2**	**Session 3**	**Session 4**	**Session 5**
	P9	Like a book	Like a book	Like a book	Like a book, finish palms up
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Parcel, box	Package	Package, box open	Open a package
	G6	Fit gesture - easy to remember	Open palms	Palm upwards	Palm upwards
Pick Up (A)	P3	Life	Life experience	Life experience	Life experience
	P6	Picking up a bag	Picking up luggage	Picking up luggage	Pick up a box
	P9	Pick up gesture	Like picking up	Like physical movement	Like physical movement
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	-	-	-	-
	G6	Fit gesture - easy to remember	Down up gesture	Down up movement	Down to up movement
Select (A)	P3	Click	Click	Click	Click
	P6	Selecting a thing	Select	Select	Select
	P9	Point	Pointing at something	Point to choose something	Point at something
	P12	Makes sense	Makes sense	By repetition	Makes sense
	G1	Pointing	Pointing/Kids gesture	Pointing	Point at something
	G6	To point and select	Index finger pointing	Index finger pointing	Pointing forward
Stop (A)	P3	Life	Push	Life experience	Life experience
	P6	Like police	Stop icon	Stop icon	Stop icon
	P9	Stop gesture	Common sign for stop	Commonly recognised stop gesture	Normal gesture for stop
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Stopping something	Stopping someone	-	Stop
	G6	Everyday gesture	Palm out	Palms up	Palm in front
Move Back (B)	P3	IT logo	IT logo	IT logo	IT logo

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Table 4.4 – *Continued from previous page*

Freehand Gesture	**Partic-ipant**	**Session 2**	**Session 3**	**Session 4**	**Session 5**
	P6	Comparing with Move Forward	Comparing with Move Forward	Comparing with Move Forward	Comparing with Move Forward
	P9	Right to left, don't know which hand	Right to left, right hand	Right to left, right hand	Right to left, right hand
	P12	By repetition	By repetition	By repetition	By repetition
	G1	-	-	-	-
	G6	Right hand gesture	Right to left gesture	Right to left movement	Right to left movement
Move Forward (B)	P3	IT logo	IT logo	IT logo	IT logo
	P6	Comparing with Move Back	Comparing with Move Back	Comparing with Move Back	Comparing with Move Back
	P9	Move left to right, can't remember which hand	Left to right, left hand	Left to right, left hand	Left to right, left hand
	P12	By repetition	By repetition	By repetition	By repetition
	G1	-	-	-	-
	G6	Left hand gesture	Left to right gesture	Left to right movement	Left to right movement
Zoom In (B)	P3	"In" is moving hands inwards	Life experience	Downwards	Downwards
	P6	Comparing with Zoom Out	Zoom inside	Comparing with Zoom Out	Comparing with Zoom Out
	P9	Letter "V" downwards	Capital "V" downwards	Capital "V" downwards	Capital "V", downwards
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Hands in	V to the inside, getting smaller	Draw V towards inside	Draw V to inside
	G6	Fit gesture	V sign downwards	V inward	V inward
Zoom Out (B)	P3	"Out" is moving hands outwards	Life experience	Upwards	Upwards
	P6	Comparing with Zoom In	Zoom outside	Comparing with Zoom In	Comparing with Zoom In

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Table 4.4 – *Continued from previous page*

Freehand Gesture	Participant	Session 2	Session 3	Session 4	Session 5
	P9	Letter ”V” upwards	Capital ”V” upwards	Capital ”V” upwards	Capital ”V” upwards
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Hands out	V to the outside	V to the outside	Draw V outside
	G6	Fit gesture - easy to remember	V sign upwards	V outward	V outward
Delete (C)	P3	Big ”X”	”X”	IT logo ”X”	IT logo ”X”
	P6	Cross	”X”	”X”	”X”
	P9	”X”	Like ”X”, delete icon	”X”, delete icon	”X”, like delete icon in software
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	-	-	-	-
	G6	-	-	-	-
Go To (C)	P3	iPad	iPad	iPad	iPad
	P6	Like a digital window to change	”Bye Bye”	”Bye Bye”	”Bye Bye”
	P9	”Wax On”	”Wax On”	”Wax On”	”Wax On”
	P12	By repetition	By repetition	By repetition	By repetition
	G1	-	-	-	-
	G6	A wave	A wave	Wave of the hand	Wave of palm
Play (C)	P3	Similar with Search which is the first gesture I learnt	Similar with Search	Similar with Search	Similar with Search
	P6	Like iTunes icon	iTunes icon	iTunes icon	iTunes icon
	P9	Circle	Circle clockwise	Clockwise circle	Clockwise circle
	P12	By repetition	By repetition	By repetition	By repetition
	G1	-	-	-	-
	G6	Similar to circle	Circle	Wave of the hand	Wave of palm
Search (C)	P3	1st one learnt	1st one learnt	1st one learnt	1st one learnt
	P6	-	Search to find something	-	-
	P9	Backwards ”9”	Like mirrored ”9”	Reverse number ”9”	Counter-clockwise, like ”9” reversed
	P12	By repetition	By repetition	By repetition	By repetition

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Table 4.4 – *Continued from previous page*

Freehand Gesture	Participant	Session 2	Session 3	Session 4	Session 5
	G1	Q- Question - Search	Q - Question	Q - Question	Draw Q - Question
	G6	An @ sign	Number 9	Circle with a tail	Circle with tail
Show Me (C)	P3	-	-	Life experience	Life experience
	P6	-	Show a thing	Showing something	Show a thing to me
	P9	Shrug, palms up	Like shrugging shoulders, palms up	Shrug shoulders, palms down	Shrug shoulders, palms up
	P12	Makes sense	Makes sense	By repetition	Makes sense
	G1	-	-	-	-
	G6	Open palms	Open palms	Both palms upward	Palm spread upward
Turn On (C)	P3	Life	Life experience	Life experience	Life experience
	P6	A radio	Like a radio	Like turning a radio on	Comparing with Turn Off
	P9	Like a switch/volume control	Like a switch or volume knob	Like a switch/volume knob	Like a switch or volume knob
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Car engine	Car key	Car engine key	Car engine - keys
	G6	Fit gesture - easy to remember	Wrist twisting open	Outward turn of wrist	Turn wrist outward
Turn Off (C)	P3	Life	Life experience	Life experience	Life experience
	P6	A radio	Turn off a radio	Turn off a radio	Turn off a radio
	P9	Like a switch/volume knob	Opposite of Turn On	Switch/volume knob, opposite of Turn On	Turn switch/volume knob off
	P12	Makes sense	Makes sense	Makes sense	Makes sense
	G1	Car Engine	Car key	Car engine key	Car engine - keys
	G6	Fit gesture - easy to remember	Wrist twisting close	Inward turn of wrist	Turn wrist inward

4.4 Discussion

Several interesting results emerge from the results reported above with regard to the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the learning of freehand gestures. In this section we discuss the results examining the effect of metaphor, introduced during participant training, on the of learning of freehand gesture (H1). First we discuss the results examining how participants in the study rated and reported their prior familiarity with the freehand gestures. We then discuss the results examining the effect of metaphor on the number of errors in retention and performance as well as on participant perception of the suitability of the freehand gestures. Next we discuss the results examining how participants in the study reported remembering the freehand gestures. Finally we discuss which type of metaphor better supported the learning of freehand gestures (H2).

4.4.1 Participant Rating and Self Reporting of their Prior Familiarity with the Freehand Gestures

The results of participant rating of prior familiarity, found no significant effect of metaphor condition. This suggests that participants in the study had similar prior experiences to one another in encountering the freehand gestures from interacting with technology, other people or everyday life.

4.4.2 Effect of Metaphor on the Number of Errors in Learning

In this section we discuss the results examining the effect of metaphor, introduced during participant training, on ease of learning (H1). Specifically, we examine the effect on the (i) number of errors in retention and (ii) number of errors in performance.

We first examined the effect of metaphor on both the number of errors in retention and performance across all freehand gestures i.e. the effect of metaphor on this freehand gesture set. The results showed that, across all sessions of the study, participants in the *no metaphor* condition made significantly more errors in both retention and performance than participants in the *task metaphor* and *performance metaphor* conditions across all sessions of the study (see Figures 4-2a and 4-3a).

Next we examine the effect of metaphor on both the number of errors in retention and performance for each Gesture Category i.e. generalised categories which group together freehand gestures based on observed differences in the levels of suitability (high, medium and low respectively) from the original freehand gesture generation study. The results showed that, across all sessions of the study, there was no effect of metaphor on the number of errors in retention.

However, participants in the *performance metaphor* condition made significantly less errors in performance than participants in the *task metaphor* and *no metaphor* condition across all Gesture Categories. In particular, as highlighted in Figure 4-3c, this effect was most notable for freehand gestures in Category B.

Overall these results suggest that metaphor, introduced during participant training, did have an effect on ease of learning with participants in the *task metaphor* and *performance metaphor* conditions making significantly fewer errors in performance than participants in the *no metaphor* condition. Furthermore, although not significant, examining the means indicates that participants in the *task metaphor* and *performance metaphor* conditions made fewer errors in retention than participants in the *no metaphor* condition.

These results help to confirm our hypothesis H1. Furthermore, these results suggest that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) does have a positive effect on the ease of learning of freehand gestures.

4.4.3 Effect of Metaphor on the Suitability of Freehand Gestures

In this section we again discuss the results examining the effect of metaphor, introduced during participant training, on ease of learning (H1). Specifically, we examine if metaphor, introduced during participant training, had an effect on the participants perception of the fit between the freehand gesture and the task.

We first examined the effect of metaphor on the perception of suitability across all freehand gestures i.e. the effect of metaphor on this freehand gesture set. The results showed that across all sessions of this study participants in the *no metaphor* condition rated the fit between the freehand gesture and the task significantly lower than participants in the *task metaphor* and *performance metaphor* conditions. There was no such significant difference between participants in the *task metaphor* and *performance metaphor* conditions.

Next we examined the effect of metaphor on the perception of suitability for each Gesture Category i.e. generalised categories which group together freehand gestures based on observed differences in the levels of suitability (high, medium and low respectively) from the original freehand gesture generation study. The results showed that participants in the *performance metaphor* condition rated the fit between the freehand gesture and the task for each Gesture Category significantly higher than participants in the *no metaphor* condition. Although not significant, participants in the *task metaphor* condition did rate the fit between the freehand gesture and the task for each Gesture Category higher than participants in the *no metaphor* condition (see Figure 4-4).

Although there was not an interaction effect between Gesture Category and metaphor condition, the results suggested that the introduction of a metaphor did affect the rating of fit between the freehand gesture and the task differently for each Gesture Category. Figure 4-5 shows the ratings of the fit between the freehand gesture and the task for each Gesture Category for each metaphor condition. Figure 4-5 suggests that for Category A the introduction of a task metaphor had a more positive effect on the rating of the fit between the freehand gesture and the task than a performance metaphor. In contrast for freehand gestures in Category B and C, Figure 4-5 suggests that the introduction of a performance metaphor had a more positive effect on this rating than a task metaphor.

These results again, help to confirm our hypothesis H1. Furthermore, these results suggest that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) does have a positive effect on the ease of learning of freehand gestures.

4.4.4 Participant Self Reporting of How They Remembered Freehand Gestures

To further examine the effect of metaphor introduced during participant training, in this section we discuss the results of participant self reporting of how they remembered the freehand gestures.

For participants in the *no metaphor* condition, self reporting of how they remembered the freehand gestures was collected over the course of the study. Participants in the *no metaphor* condition often reported that they remembered the freehand gesture from "life experience" or because it "makes sense" or "by repetition". These reported metaphor are less rich than those reported by participants in the *task metaphor* and *performance metaphor* conditions.

Where a metaphor was provided, participants in the *no metaphor* condition often reported a performance like metaphor (i.e. a metaphor which describes the shape and movement of the hands). Interestingly, this was for all freehand gestures regardless of Gesture Category. Often the originally reported metaphor in session 2 was broadly the same when reported in session 5. Where the metaphor did change this was often due to the addition of an important physical feature of the freehand gesture. For example, for the freehand gesture *Play* one reported metaphor in session 2 was a "circle" which was modified to "clockwise circle" in session 5.

As discussed in Section 4.1, the metaphor presented to participants should "support the areas in that the users' understanding is the weakest" (Erickson [1990]). These results suggest that user understanding is weakest in understanding how to perform the freehand gesture

For participants in the *task metaphor* and *performance metaphor* conditions, self reporting of how they remembered the freehand gestures was collected at the end of session 5. Participants in the *task metaphor* and *performance metaphor* conditions reported a wide range of different metaphors used to remember the freehand gestures. Interestingly, the majority of the reported metaphors are not the metaphors presented to participants during training.

Furthermore, the reported metaphors by participants in the *task metaphor* and *performance metaphor* conditions were predominately task like metaphors (i.e. a metaphor which explains the freehand gesture in terms of an example user task) for freehand gestures in Category A. Whereas, for freehand gestures in Categories B and C the reported metaphors were predominately performance like metaphors (i.e. a metaphor which describes the physical shape and movement of the freehand gesture).

Interestingly, this observation corresponds to the results reported above where, for freehand gestures in Category A a task metaphor better supports participant perception of the suitability of freehand gestures and for freehand gestures in Category B and C a performance metaphor better supports participant perception of the suitability of freehand gestures. Similarly, examining the errors in retention, participants presented with a task metaphor made fewer errors in retention for freehand gestures in Category A however, participants presented with a performance metaphor made fewer errors in retention for freehand gestures in Category B and C. Examining the errors in performance, participants presented with a performance metaphor made fewer errors in performance for freehand gestures in Category B however, for Category A and C participants made similar numbers of errors in performance.

From these results a number of interesting observations emerge. Firstly, comparing the reported metaphors by participants in the *task metaphor* and *performance metaphor* conditions to participants in the *no metaphor* condition, suggests that the introduction of a metaphor during participant training does support mindful abstraction. Participants in the *task metaphor* and *performance metaphor* conditions reported a number of different metaphors whereas participants in the *no metaphor* condition often either did not report a metaphor or reported that it "makes sense" or "by repetition".

Furthermore, when asked to report how they remembered a freehand gesture, participants in the *task metaphor* and *performance metaphor* conditions often did not report the metaphor presented during training. This suggests that it was not the specific metaphor which supported ease of learning rather, by presenting a metaphor during training we were supporting participants to think about the freehand gesture they were being trained on. This is in line with the literature which suggest that teaching people to think about an activity they usually perform mindlessly improves their performance.

Secondly, examining the reported metaphors by participants in the *task metaphor* and *performance metaphor* conditions, shows that a task like metaphor is reported for freehand gestures in Category A whereas a performance like metaphor is reported for freehand gestures in Category B and C. This might suggest that to further support mindful abstraction, different types of metaphor might be presented to users depending on the predicted suitability of the freehand gesture, i.e. its Gesture Category. That is, where there predicted suitability is high i.e. where the generating participants proposed few freehand gestures, there are high agreement and guessability scores as well as when freehand gestures can be categorised as a highly formal emblem gestures, a task metaphor might better supports mindful abstraction.

Conversely, where there predicted suitability is low i.e. where the generating participants proposed many different freehand gestures, there are average or low agreement and guessability scores as well as when freehand gestures can be categorised as either semi-formal mime gestures or highly improvised gesticulation gestures, a performance metaphor might better supports mindful abstraction.

Furthermore, as highlighted above, this observation corresponds to the results of participants in the *task metaphor* and *performance metaphor* conditions perception of the suitability of freehand gestures as well as the differences in the number of errors in retention and performance.

4.4.5 Does a Task Metaphor or performance metaphor Better Support the Ease of Learning of Freehand Gestures?

In this section we discuss which type of metaphor better supports the learning of freehand gestures (H2). To address H2 we discuss the results from both a designers/experimenters perspective as well as from a user/participant perspective. From a designers/experimenters perspective we discuss the results regarding the effect of metaphor on number of errors in retention and performance. From a user/participant perspective we discuss the results of participant reporting of 1. the fit between the freehand gesture and the task and 2. how they remembered the freehand gestures.

Examining the effect of metaphor on the number of errors in retention and performance across all freehand gestures showed that across all sessions of the study participants in both the *task metaphor* and *performance metaphor* conditions produced similar numbers of errors in retention and performance.

Similarly, examining the number of errors in retention across Gesture Categories showed that across all sessions of the study participants in both the *task metaphor* and *performance metaphor* conditions produced similar numbers of errors in retention. However, examining the number of errors in performance across Gesture Categories showed that overall, the introduction of a performance metaphor significantly reduces the number of errors in performance.

Therefore, from a designers/experimenters perspective we can confirm our hypothesis H2. That is, the results indicate that a performance metaphor has a more positive effect on reducing the number of errors in performance when compared to a task metaphor.

Examining the effect of metaphor on participant rating of fit between the freehand gesture and the task shows that across all freehand gestures, participants in both the *task metaphor* and *performance metaphor* conditions rated the suitability of the freehand gestures similarly. However, examining the participant rating of fit between the freehand gesture and the task across Gesture Categories showed that overall participants in the *performance metaphor* condition rated this fit higher than participants in the *no metaphor* condition.

When asked to report how they remembered a freehand gesture, participants in the *task metaphor* and *performance metaphor* conditions often did not report the metaphor presented during training. This suggests that it was not the specific metaphor which supported ease of learning rather, by presenting a metaphor during training we were supporting the participants to think about the freehand gesture they were being trained on. Examining further these reported metaphors, shows that a task like metaphor is reported for freehand gestures in Category A whereas a performance like metaphor is reported for freehand gestures in Category B and C.

Therefore, from a user/participant perspective, we can partially confirm our hypothesis H2. H2 is partially confirmed as, participants presented with a performance metaphor during training rate the fit between the freehand gesture and the task higher across all Gesture Categories than participants not presented with a metaphor during training.

However, examining further the fit between the freehand gesture and the task and how participants reported remembering the freehand gestures, suggests that from a user/participant perspective 1. a task metaphor better supports learning of freehand gestures in Category A and 2. a performance metaphor better supports learning of freehand gestures in Category B and C.

4.4.6 Limitations

One limitation to the study presented above is that participants are trained on the freehand gestures by referencing only its interaction task (e.g. *Open, Play* or *Zoom In*). This presention of the freehand gestures in the abstract removes the context in which they might be used for interaction with different devices and applications. We believe this makes learning more challenging and allows for a better examination of ease of learning and the effect of supporting both mechanisms of transfer of learning on the ease of learning of freehand gestures.

However, the freehand gestures in our freehand gesture set were selected by maximising suitability across both interaction tasks and user tasks. That is, maximising the suitability of selected freehand gestures to perform the generalised interaction, as well as, an instance of this freehand gestures use on an imagined device or application. By training participants by only referencing the interaction task perhaps we have reduced the suitability of selected freehand gestures. This limitation might explain why participants in this study did not rate the suitability of freehand gestures in Category B and C significantly differently.

Another limitation to the study presented above is that the metaphors are generated by a small group of designers. Wobbrock et al. [2009] highlights that gestures generated by a large group of potential end users are preferred over gestures generated by a small group of designers. Similarly, users might prefer metaphors generated by a large group of potential end users than those generated by a small group of designers.

Furthermore, although the metaphors generated for this study were selected by consensus between a small group of designers, there is no way of measuring if each metaphor is equally suitable. This is a particular limitation for the task and performance metaphors presented to participants for the same freehand gesture. For example, is the task metaphor for *Open* equally as suitable as the performance metaphor for *Open*? Although the results seem to suggest that it is not the specific metaphor but rather by presenting a metaphor during training we support participants in thinking about the freehand gesture they are being trained on, it might be the case that for example, the performance metaphor for a given freehand gesture is more suitable and therefore better supports mindful abstraction when compared to the corresponding task metaphor.

To address these limitations, in the following chapter we examine how potential end users can generate suitable metaphors. We also examine how potential end user can rate these generated metaphors such that suitable metaphors are selected for subsequent use as well as ensuring that for a given freehand gesture, the task metaphor and performance metaphor are equally well rated. Furthermore, to validate the findings in this chapter, as part of the study presented in the following chapter we examine the effect of supporting both mechanisms of transfer of learning on the ease of learning of freehand gestures. However, we examine this effect when participants are trained on freehand gestures by reference to an example user task for example, *to open a document* rather than the abstract interaction task *Open*.

4.5 Corroborating the Results from Chapter 3

In this section attempt to corroborate the results reported in Chapter 3, Section 3.2. That is, we wish to corroborate the results that (i) as the rating of the fit between the freehand gesture and the task increases, the number of errors in learning decreases, (ii) the Gesture Categories do provide an indication as to the suitability of a freehand gesture and (iii) the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture.

We consider only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. Furthermore, in Chapter 3 Section 3.2, one limitation is the short time between the training session and learning assessment session from which the results were analysed. Therefore, in the results presented below we consider the rating of the fit between the gesture and the task and the errors in retention and performance both immediately after training (session 2) as well as after an intervening period of 7 days (session 3).

Hypotheses

As in Chapter 3 we hypothesis that,

H-V1: The better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture

H-V2: Freehand gestures in Category A will be rated by our participants as a better fit to their respective tasks than freehand gestures in Category B, which in turn will be rated as having better task fit than freehand gestures in Category C

H-V3: Freehand gestures in Category A will have in fewer errors in learning than gestures in freehand gestures in Category B, which in turn will have fewer errors in learning than freehand gestures in Category C

Participants

We consider only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. This was a total of 6 participants aged from 25 to 30 with a mean age of 27. 4 participants were male and 2 were female. All participants were right-handed.

Results

Suitability and Ease of Learning

The results reported in this section address if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture (H-V1). We examine the relationship between our participants rating of freehand gestures in response to the question, *"how much you felt the action of the gesture related to the function of the gesture"* and the number of errors in learning made both (i) immediately after training (session 2) and (ii) after an intervening period of 7 days (session 3).

From the results taken immediately after training (session 2), a Pearson product-moment correlation showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased ($r(88)=-0.399$, $p<0.001$). After an intervening period of 7 days (session 3), a Pearson product-moment correlation again showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased ($r(88)=-0.376$, $p<0.001$).

This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate, or predict, ease of learning of freehand gestures and confirms our hypothesis H-V1.

Gesture Categories and the Suitability of a Freehand Gesture

The results reported in this section address if the Gesture Categories proposed in Chapter 3 Section 3.1 do provide an indication as to the suitability of a freehand gesture (H-V2). We examine the ratings of the fit between the freehand gesture and the task for each Gesture Category by our participants both (i) immediately after training (session 2) and (ii) after an intervening period of 7 days (session 3).

Tables 4.5 and 4.6 show a summary of the ratings participants gave for each freehand gesture in this study in response to the question, *"how much you felt the action of the gesture related to the function of the gesture"* after each session.

From these tables we can see that overall participants rate freehand gestures in Category A as very well matched their tasks with the notable exception of *Move*. Category B freehand gestures are, as predicted, not rated as highly as Category A freehand gestures. Interestingly, participants rate the freehand gestures *Zoom In* and *Zoom Out* as well matched to their interaction tasks whereas the freehand gestures *Move Back* and *Move Forward* were rated as not well matched to their interaction tasks. Category C freehand gesture, again as predicted, are rated as not well matched to their interaction tasks with the notable exceptions of *Delete, Turn On* and *Turn Off*.

The mean rating of freehand gestures, taken immediately after training (session 2), in Category A is 8.20 (*sd*=1.29), for Category B is 5.45 (*sd*=2.25) and for Category C is 6.06 (*sd*=0.90). The mean rating of freehand gestures, taken after an intervening period of 7 days (session 3), in Category A is 8.34 (*sd*=1.08), for Category B is 6.0 (*sd*=1.36) and for Category C is 6.91 (*sd*=0.91).

To further examine the relationship between the Gesture Categories and the ratings of the fit between the freehand gesture and the task we conducted a one-way ANOVA test. From the results taken immediately after training (session 2), this test reports that there was a statistically significant difference in our participants ratings of the fit between the freehand gesture and the task across the three Gesture Categories (F=7.445, p=0.001). Post hoc Tukey tests indicated that freehand gestures in Category A were rated significantly higher than freehand gestures in Category B (p=0.012) and freehand gestures in Category C (p=0.002). There was no such significant different between freehand gestures in Category B and Category C (p=0.996).

After an intervening period of 7 days (session 3), a one-way ANOVA reports that there was a statistically significant difference in our participants ratings of the fit between the freehand gesture and the task across the three Gesture Categories (F=8.037, p=0.001). Post hoc Tukey tests indicated that freehand gestures in Category A were rated significantly higher than freehand gestures in Category B (p=0.001) and freehand gestures in Category C (p=0.021). There was no such significant different between freehand gestures in Category B and Category C (p=0.30).

These results partially support our hypothesis H-V2. The results suggest, as reported in Chapter 3 Section 3.2, that Gesture Categories do provide a broad indication as to the suitability of a freehand gesture. H-V2 is partially supported as participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, rated the suitability of the freehand gestures in Category A higher than freehand gestures in Category B and Category C. However, participants in this study did not rate the suitability of the freehand gestures in Category B and Category C significantly different.

Table 4.5: Participant Rating of the Suitability (i.e. Rating of the Fit Between the Freehand Gesture and the Task) of the Freehand Gestures by Participants in the *No Metaphor* Condition Recorded Immediately after Training (Session 2).

Freehand Gesture	**Gesture Category**	**Low (1-4)**	**Average (5-7)**	**High (8-10)**	**Mean Rating**
Stop	A	0	2	3	9.4
Select	A	0	1	4	8.8
Drop	A	0	1	4	8.6
Pick Up	A	0	1	4	8.2
Open	A	0	3	2	8.0
Close	A	0	3	2	7.8
Move	A	0	0	5	6.6
Zoom In	B	1	2	2	7.0
Zoom Out	B	2	1	2	7.0
Move Forward	B	1	3	1	4.0
Move Back	B	2	2	1	3.8
Turn Off	C	0	0	5	8.8
Turn On	C	1	0	4	8.8
Delete	C	0	1	4	8.6
Show Me	C	2	3	0	6.6
Play	C	3	1	1	5.6
Go To	C	2	3	0	5.0
Search	C	2	3	0	4.0

Table 4.6: Participant Rating of the Suitability (i.e. Rating of the Fit Between the Freehand Gesture and the Task) of the Freehand Gestures by Participants in the *No Metaphor* Condition Recorded After a Intervening Period of 7 days (Session 3).

Freehand Gesture	**Gesture Category**	**Low (1-4)**	**Average (5-7)**	**High (8-10)**	**Mean Rating**
Stop	A	0	0	5	9.6
Drop	A	0	1	4	8.6
Pick Up	A	0	1	4	8.6
Close	A	0	1	4	8.4
Open	A	0	1	4	8.4
Select	A	0	1	4	8.4
Move	A	2	1	2	6.4
Zoom In	B	0	2	3	7.8
Zoom Out	B	0	2	3	7.8
Move Back	B	4	0	1	4.2
Move Forward	B	4	0	1	4.2
Turn On	C	0	1	4	8.8
Turn Off	C	0	1	4	8.8
Delete	C	0	1	4	8.4
Show Me	C	0	5	0	6.4
Go To	C	2	1	2	5.8
Play	C	3	0	5	5.6
Search	C	2	3	0	4.6

Gesture Categories and Ease of Learning

The results reported in this section address whether the indication of the suitability of a freehand gestures provided by its Gesture Category also provides an indication as to the ease of learning of the freehand gesture (H-V3). Again we examine ease of learning for each Gesture Category by our participants both (i) immediately after training (session 2) and (ii) after an intervening period of 7 days (session 3). Where ease of learning was assessed as the number of errors in 1. retention and 2. performance.

Tables 4.7 and 4.8 show the number of errors made by participants in retention and performance. From these tables we can see that Category A freehand gestures, as expected, produced the few errors in both retention and performance. However, there was a larger number of errors in retention for the freehand gesture *Move* in session 2 compared to the other freehand gestures in Category A.

In Category B the freehand gestures *Move Forward* and *Move Back* produced the highest errors in performance in both session 2 and session 3. Participants often performed the freehand gesture using the wrong hand (e.g. using the right hand to perform the *Move Forward* freehand gesture instead of the left) or direction (e.g. moving the hand from right to left to perform the *Move Forward* freehand gesture rather than left to right). Interestingly, the freehand gestures *Zoom In* and *Zoom Out* produced few errors in performance in both session 2 and session 3.

Category C freehand gestures produced a split in the number of errors in either retention or performance. In sessions 2 and 3, all freehand gestures with the exception of *Go To* produced an unexpectedly low number of errors in retention. However, as would be expected, in sessions 2 and 3 all freehand gestures, with the exception of *Go To* and *Show Me*, produced low numbers of errors in performance.

To examine the relationship between the Gesture Categories and the number of errors in retention we conducted a one-way ANOVA test. From the results taken immediately after training (session 2), this test reports that there is no significant difference in the number of errors in retention made by participants across the three Gesture Categories (F=0.215, p=0.807).

After an intervening period of 7 days (session 3), a one-way ANOVA reports that there was a statistically significant difference in the number of errors in retention across the three Gesture Categories (F=3.281, p=0.042). Post hoc Tukey tests indicated that freehand gestures in Category A produced fewer errors in retention than freehand gestures in Category B (p=0.05). However, there was no such significant different between freehand gestures in Category A and Category C (p=0.120) or between freehand gestures in Category B and Category C (p=0.817).

Similarly, examining the number of errors in performance a one-way ANOVA test from the results taken immediately after training (session 2), reports that there is no significant difference in the number of errors in retention made by participants across the three Gesture Categories (F=1.939, p=0.150).

After an intervening period of 7 days (session 3), a one-way ANOVA reports that there was a statistically significant difference in the number of errors in performance across the three Gesture Categories (F=3.101, p=0.05). Post hoc Tukey tests indicated that freehand gestures in Category A produced fewer errors in performance than freehand gestures in Category B (p=0.05). However, there was no such significant different between freehand gestures in Category A and Category C (p=0.973) or between freehand gestures in Category B and Category C (p=0.106).

These results suggest that we can partially confirm our hypothesis H-V3. Examining the mean number of errors in learning shows that, as expected, freehand gestures in Category A produce the lowest number of errors in both retention and performance in both session 2 and session 3. Similarly, as expected participants made more errors in performance for freehand gestures in Category B than and Category C. However, in this study participants made more errors in retention for freehand gestures in Category B than freehand gestures in Category C.

Table 4.7: Errors Made by Participants in the *No Metaphor* Condition in Retention and Performance Recorded Immediately after Training (Session 2)

Freehand Gesture	**Gesture Category**	**No. Errors: Retention**	**No. Errors: Performance**
Pick Up	A	0	0
Stop	A	1	0
Select	A	1	1
Drop	A	1	2
Open	A	1	2
Close	A	2	1
Move	A	6	3
Zoom In	B	0	0
Zoom Out	B	0	0
Move Forward	B	3	8
Move Back	B	4	8
Delete	C	0	0
Turn Off	C	0	0
Turn On	C	0	1
Play	C	2	0
Search	C	0	3
Show Me	C	3	6
Go To	C	12	5

Table 4.8: Errors Made by Participants in the *No Metaphor* Condition in Retention and Performance Recorded After a Intervening Period of 7 days (Session 3)

Freehand Gesture	**Gesture Category**	**No. Errors: Retention**	**No. Errors: Performance**
Drop	A	0	0
Open	A	0	0
Pick Up	A	0	0
Close	A	0	1
Select	A	0	1
Stop	A	0	1
Move	A	1	1
Zoom In	B	1	0
Zoom Out	B	0	1
Move Forward	B	1	4
Move Back	B	4	4
Delete	C	0	0
Play	C	0	0
Turn On	C	0	0
Turn Off	C	0	0
Search	C	1	1
Show Me	C	1	2
Go To	C	6	2

Discussion

In this section we discuss the results which attempted to corroborate the results reported in Chapter 3. We discuss the results examining (i) the relationship between participants rating of the fit between the freehand gesture and the task (i.e. the suitability of the freehand gesture for the given interaction task) and the number of errors in learning (H-V1), (ii) if the Gesture Categories do provide an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated (H-V2) and (iii) if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture (H-V3).

To corroborate the results from Chapter 3 we considered only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. Furthermore, in Chapter 3 Section 3.2, one of the identified limitations was the short time between the training session and learning assessment session from which the results were analysed. To address this limitation we considered the rating of the fit between the gesture and the task as well as the errors in learning both immediately after training (session 2) as well as after an intervening period of 7 days (session 3).

Suitability and Ease of Learning

First we examined if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture (H-V1). The results of a correlation analysis showed, that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased. This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate ease of learning of freehand gestures and confirms our hypothesis H-V1.

As discussed in Chapter 3 Section 3.3, this relationship provides a way of evaluating and comparing freehand gestures. That is, by comparing different ratings of the fit between the freehand gesture and the task we can compare different freehand gestures evaluating both the suitability for the given task as well as ease of learning.

Gesture Categories and the Suitability of a Freehand Gesture

Next we examined if the Gesture Categories proposed in Chapter 3 Section 3.1 do provide an indication as to the suitability of a freehand gesture (H-V2). The results taken both immediately after training (session 2) and after a intervening period of 7 days (session 3) show that, participants rated freehand gestures in Category A significantly higher than freehand gestures in Category B and Category C. However, freehand gestures in Category B and Category C were not rated significantly differently.

These results suggest that we should reject out hypothesis H-V2 as, although freehand gestures in Category A were rated significantly higher than freehand gestures in Category B and C, there was no significant difference between the ratings of freehand gestures in Category B and C. Indeed examining the mean rating of freehand gestures in Category B and C showed that overall participants rated the suitability of freehand gestures in Category C higher in both sessions than the freehand gestures in Category B.

However, further examination of these results suggests they were broadly consistent with how freehand gestures were grouped together into Gesture Categories from the results of the original freehand gesture generation study.

Examining participant ratings of suitability showed that in general freehand gestures in Category A had (i) a high rating of suitability and (ii) a higher rating of suitability than freehand gestures in Category B and C (see Tables 4.7 and 4.8). This is as predicted and consistent with how freehand gestures in Category A were grouped together from the results of the original freehand gesture generation study - i.e. Category A groups together selected freehand gestures where the majority of participants proposed one freehand gesture for that interaction task (and corresponding user tasks) with only a few participants proposing alternatives, they are highly formal emblem gestures which draw on the users' prior experience and familiarity with the freehand gesture as used in everyday human communication.

For freehand gestures in Category B across both session 2 and session 3 (see Tables 4.7 and 4.8), participants rated the freehand gestures *Zoom In* and *Zoom Out* as well suited to the task (both had a mean rating of 7.8) whereas the freehand gestures *Move Back* and *Move Forward* were not rated as well suited to the task (both had a mean rating of 4.2). This suggests that where the direction and orientation of the hands are as expected by the participant, freehand gestures have a good rating of suitability (i.e. *Zoom In* and *Zoom Out*). However, where the direction and orientation of the hands are not as expected by the participant, the freehand gestures have a low rating of suitability (i.e. *Move Back* and *Move Forward*).

This result is consistent with how freehand gestures in Category B were grouped together from the results of the original freehand gesture generation study - i.e. Category B groups together selected freehand gestures where participants proposed a range of freehand gestures which typically differed in the direction or orientation of the hands however, broadly the proposed freehand gestures were similar, they are semi-formal mime gestures where differences in the spatial cognition or spatial frame of the generating participants and the new user will likely impact on ease of learning.

For freehand gestures in Category C across both session 2 and session 3 (see Tables 4.7 and 4.8), participants rated *Go To, Play, Search* and *Show Me* as not well suited to the task whereas, *Turn On, Turn Off* and *Delete* as well suited to the task.

Again , this result is consistent with how freehand gestures in Category C were grouped together from the results of the freehand gesture generation study. Prior to the start of this study we would predict that all freehand gestures in Category C would be rated as not well suited to the task. This is because although freehand gestures in Category C were selected by maximising the consensus between participants that it is the most suitable for the task, given the wide range of proposed freehand gestures, the selected freehand gestures are in effect arbitrary freehand gestures for that task. Furthermore, the proposed freehand gestures are largely improvised gesticulation gestures which convey ideas rather than manipulations or commands. For the freehand gestures *Go To, Play, Search* and *Show Me* this arbitrary selection of freehand gestures is reflected in the low rating of suitability. Interestingly, for the freehand gestures *Turn On, Turn Off* and *Delete*, this arbitrary selection has resulted in the selection of freehand gestures with a high rating of suitability.

Overall, these results suggest that we can partially confirm our hypothesis H-V2. H-V2 is partially supported as participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, rate the suitability of the freehand gestures broadly in line with how the Gesture Categories group together selected freehand gestures based on their different levels of suitability (high, medium and low respectively) from the original freehand gesture generation study.

Gesture Categories and Ease of Learning

Finally, we examined if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture (H-V3). The results taken immediately after training (session 2) show that there was no significant difference in the number of errors in retention or performance made by participants across the three Gesture Categories. However, the results taken after a intervening period of 7 days (session 3) reported a significant difference in the number of errors in retention and performance made by participants across the three Gesture Categories.

Examining the errors in retention showed that, as expected, freehand gestures in Category A produced fewer errors in retention than freehand gestures in Category B and C. However, further examination of the means showed unexpectedly that freehand gestures in Category B produced more errors in retention than Category C.

Examining the errors in performance showed that, as expected, freehand gestures in Category A produced fewer errors in performance than freehand gestures in Category B and C. Further examination of the means showed that as expected, freehand gestures in Category B produced more errors in performance than Category C.

These results suggest that, similar to our hypothesis H-V2, we can partially confirm our hypothesis H-V3. H-V3 is partially supported as participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, as expected, made fewer errors in both retention and performance for freehand gestures in Category A in both session 2 and 3. Similarly, as expected participants made more errors in performance for freehand gestures in Category B than and Category C. However, in this study participants made more errors in retention for freehand gestures in Category B than freehand gestures in Category C.

Summary

Overall, the results reported above indicate that participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, made fewer errors in learning (i.e. retention and performance) for freehand gestures with a high rating of suitability and more errors for freehand gesture with a low rating of suitability (H-V1).

Furthermore, the results indicate that Gesture Categories do provide an indication as to the perception of suitability of the freehand gestures for users other than by whom they were generated. That is, high, medium and low perceptions of suitability for Category A, B and C respectively (H-V2).

Similarly, the results indicate that Gesture Categories do provide a broad prediction as to the ease of learning of the freehand gestures in that Category. Additionally, the results of the number of errors in retention and performance suggest that Gesture Categories can provide an indication as to the types of errors most likely to be observed. That is, Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

4.6 Chapter Summary

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]).

In this chapter we investigated how to support mindful abstraction and the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures. Specifically, this chapter investigated,

R02: How can we use metaphor to support mindful abstraction?

R03: How can we support both mechanisms of transfer of learning for new users of freehand gestures?

R04: Does supporting both mechanisms of transfer of learning make freehand gestures easier to learn for new users?

The study presented consisted of two phases - Immediate Learning Phase and Delayed Learning Phase. In the Immediate Learning Phase, participants were trained on the freehand gesture set proposed in Chapter 3. To support mindful abstraction we proposed that a metaphor be introduced during participant training. Participants were divided into three condition - *task metaphor*, *performance metaphor* and *no metaphor* condition. In the *task metaphor* condition participants were presented with a metaphor which explained the freehand gesture in terms of an example user task (e.g. "as though you are widening a view"). In the *performance metaphor* condition participants were presented with a metaphor which described the physical shape and movement of the freehand gesture (e.g. "looks like drawing the letter V"). In the *no metaphor* condition no metaphor was presented to participants during training.

Immediately after training, the participants learning of the freehand gestures was assessed. Learning was assessed as the number of errors in 1. retention and 2. accuracy of performance.

An error in retention was recorded if the participant forgot or performed the wrong freehand gesture therefore requiring them to be retrained. Incorrect performance was assessed as the freehand gesture not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement as demonstrated during training.

The Delayed Learning Phase was administered 7 days, 14 days and 21 days after the Immediate Learning Phase. Participants learning of the freehand gestures was again assessed.

The results of the study showed that supporting both mechanisms of transfer of learning does significantly support the learning of freehand gestures. Examining the effect of metaphor on the number of errors in retention and performance across all freehand gestures i.e. the effect of metaphor on this particular freehand gesture set, showed that across all sessions of this study participants in both the *task metaphor* and *performance metaphor* conditions produced similar numbers of errors.

Examining the number of errors in retention across Gesture Categories i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability, showed no effect of metaphor. However, examining the number of errors in performance across Gesture Categories showed that overall the introduction of a performance metaphor significantly reduces the number of errors in performance.

Therefore, from a designers/experimenters perspective the results indicate that a performance metaphor provides better support overall for participant learning of freehand gestures. That is, a performance metaphor has a more positive effect on reducing the number of errors in performance when compared to a task metaphor.

Examining the effect of metaphor on the participant rating of fit between the freehand gesture and the task showed that, across all freehand gestures participants in both the *task metaphor* and *performance metaphor* conditions rated the suitability of the freehand gestures similarly. However, examining participant ratings of the fit between the freehand gesture and the task across Gesture Categories showed that overall, participants in the *performance metaphor* condition rated this fit higher than participants in the *no metaphor* condition.

Interestingly, when asked to report how they remembered the freehand gesture, participants in the *task metaphor* and *performance metaphor* conditions often did not report the metaphor presented during training. This suggests that it was not the specific metaphor which supported ease of learning rather, by presenting a metaphor during training we were supporting the participants to think about the freehand gesture they were being trained on i.e. supporting mindful abstraction.

Furthermore, examining the reported metaphors by participants in the *task metaphor* and *performance metaphor* conditions, showed that a task like metaphor was reported where the fit between the freehand gesture and the task was high (i.e. freehand gestures from Category A). Conversely, a performance like metaphor was reported where the fit between the freehand gesture and the task was low (i.e. freehand gestures from Category B and C).

Therefore, from a user/participant perspective, the results again indicated that a performance metaphor provides better support overall for participant learning of freehand gestures. However, examining further the fit between the freehand gesture and the task and how participants reported remembering the freehand gestures suggests that from a user/participant perspective 1. a task metaphor better supports learning of freehand gestures from Category A and 2. a performance metaphor better supports learning of freehand gestures from Category B and C.

Finally, in this chapter we attempted to validate the results from Chapter 3 examining (i) the relationship between participant rating of the fit between the freehand gesture and the task and the number of errors in learning, (ii) if the Gesture Categories do provide an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (iii) if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture.

We considered only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. Furthermore, in Chapter 3 Section 3.2, one limitation was the short time between the training session and learning assessment session from which the results were analysed. Therefore, we examined the errors in learning and the rating of the fit between the freehand gesture and the task both, immediately after training as well as after an intervening period of 7 days.

Addressing (i), the results showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased. This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate ease of learning of freehand gestures.

Addressing (ii) and (iii), the results showed that freehand gestures from Category A were rated as significantly more suitable than freehand gestures from Category B and C. This was both immediately after training as well as after an intervening period of 7 days. Unexpectedly, examining the mean rating of freehand gestures from Category B and C showed that participants rate freehand gestures in Category C higher than freehand gesture in Category B in both sessions.

Furthermore, the results showed that there was no difference in the number of errors made in both retention and performance immediately after training. After an intervening period of 7 days, the results showed that freehand gestures from Category A produced significantly fewer errors in retention and performance than freehand gestures from Category B and C. There was no significant difference in the number of errors in retention and performance, for freehand gestures from Category B and C. Unexpectedly, the results showed that freehand gestures in Category B produced more errors in retention than Category C. However, as expected, freehand gestures in Category B produced more errors in performance than Category C.

These results suggest that the Gesture Categories do provide a broad indication of the suitability of freehand gestures. That is, fewer errors in learning (either retention or performance) are made for freehand gestures with a high rating of suitability and more errors for freehand gesture with a low rating of suitability. Where these different levels of suitability are broadly indicated by the Gesture Categories.

Additionally, as reported in Chapter 3 Section 3.2, the results reported regarding errors in retention and performance suggest that Gesture Categories provide an indication as to the types of errors most likely to be observed. That is, Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

Overall, the results reported in this chapter indicate that supporting both mechanisms of transfer of learning does significantly support the learning of freehand gestures. In the next chapter we build on these results and investigate whether supporting both mechanisms of transfer of learning does support the transfer of learning of freehand gestures.

Chapter 5

Supporting Mindful Abstraction and Investigating the Transfer of Learning of Freehand Gestures

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]).

In Chapter 3 we investigated how, by drawing on the prior knowledge and experience of end users, we can support the mechanism of transfer of learning, learning to automaticity. In Chapter 4 we investigated how to support mindful abstraction through the use of metaphor introduced during pre-use training. Furthermore, in Chapter 4 we experimentally tested the observation made in the literature that there are advantages to supporting both mechanisms of transfer of learning, examining the effect on the learning of freehand gestures.

Building on the results of Chapter 4, in this chapter we investigate the transfer of learning of freehand gestures. This chapter experimentally tests the observation made in the literature that there are advantages to supporting both mechanisms of transfer of learning, examining the effect on the transfer of learning of freehand gestures.

In the remainder of this chapter we first present two online questionnaires which further explore the introduction of metaphor during pre-use training to support mindful abstraction. The first online questionnaire investigates how potential end users can generate suitable task and performance metaphors. The second online questionnaire investigates how potential end user can rate these generated metaphors so that suitable metaphors are selected for subsequent use, ensuring that for a given freehand gesture the task metaphor and performance metaphor are equally well rated.

Next we present two related studies examining the transfer of learning of freehand gestures. The two studies presented consist of two phases - *Training Phase* and *Transfer of Learning Phase*. The *Training Phase* consists of 2 sessions. In session 1 participants are trained on the freehand gesture set generated in Chapter 3. Participants are trained on the freehand gestures with reference to an example user task e.g. "to open a web browser..." or "to stop a video...". Participants are then sent away and asked to return after 7 days to complete session 2. In session 2, participants are tested, and if required, retrained so as to be able to correctly remember and accurately perform each freehand gesture for the corresponding user task. Participants are again sent away and asked to return after 7 days to complete the *Transfer of Learning Phase* of the study.

The *Transfer of Learning Phase* again, consists of 2 sessions. In both sessions 3 and 4, participants are read aloud a new set of user tasks and asked to perform the freehand gesture which they feel would best perform that user task. For each freehand gesture, two new user tasks are presented; a *Directed* task which contains the same verb for the freehand gesture as presented in the training user task (e.g. "to stop the audio guide" or "to stop recording") and an *Open Ended* task which uses a synonym of the verb for the freehand gesture presented in the training user task (e.g. "to finish listening to a podcast" or "to end all notifications").

In Study I, participants are told to only use those freehand gestures which they have been trained on. In Study II, participants are told to use any freehand gesture they feel best performs the task and are not constrained to those freehand gestures which they have been trained on.

In both studies transfer of learning is assessed to have occurred, from a designers/experimenters perspective, if participants perform the freehand gesture sought for prior to the study by the experimenter. Additionally, participant perception of the suitability of the performed freehand gesture for the new user task is used to assess transfer of learning from a user/participant perspective.

The studies presented in this chapter contribute to our research objectives by investigating the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. Specifically, this chapter investigates,

R02: How can we use metaphor to support mindful abstraction?

R05: Does supporting both mechanisms of transfer of learning make it easier for users to transfer learnt freehand gestures?

5.1 User Generated Metaphors

To support mindful abstraction, in Chapter 4 a metaphor for each freehand gesture was presented to participants during training. These metaphors were generated by the researchers (see Section 4.1). The results from Chapter 4 show that supporting both mechanisms of transfer of learning does significantly support the learning of freehand gestures. That is, participants trained on the freehand gesture set generated to support learning to automaticity, with the introduction of a metaphor during training to support mindful abstraction, produced fewer errors in retention and performance than participants where no metaphor was introduced during training.

However, one possible limitation to the study presented in Chapter 4, was that the metaphors were generated by a small group of researchers and there was no way of measuring if each metaphor was equally suitable. For example, was the task metaphor for *Open* equally as suitable as the performance metaphor for *Open*?

Although the results suggested that it was not the specific task or performance metaphor, but rather that by presenting a metaphor during training mindful abstraction is supported, to address this potential limitation we conducted two online questionnaires. The first online questionnaire asks participants to generate either a task metaphor or a performance metaphor for each freehand gesture in our freehand gesture set. The second online questionnaire asks participants to rate these generated metaphors.

5.1.1 Generating Metaphors Questionnaire

In the first online questionnaire participants were asked to generate a metaphor for either 1. an example task where you might use this gesture (i.e. a task metaphor) or 2. the overall shape and movement of the gesture (i.e. a performance metaphor).

Procedure

Participants were randomly allocated to either generating a *task metaphor* or a *performance metaphor* generation condition. Participants were provided with introductory text which explained the purpose of the questionnaire. Under this introductory text was the participant instructions, examples and a practice question. Participants in the *task metaphor* condition were asked to *"describe to another person what task you might perform with that gesture"*. Participants in the *performance metaphor* condition were asked to *"describe to another person how to perform the gesture based on its overall shape and movement"*. Participants were provided with two examples which showed a video of a freehand gesture not in our freehand gesture set and an example metaphor. Participants were provided with a further example freehand gesture and invited to write down a metaphor which they could compare to an example answer (initially hidden but could be viewed once the text box was filled in).

Following the presentation of instructions, examples and a consent form page, participants were shown each freehand gesture in the freehand gesture set and asked to generate a metaphor (described in the questionnaire as "to describe to another person..."). The order in which freehand gestures were presented to participants was randomised. See Appendix C.1.1 for each of the forms presented to participants in this online questionnaire.

Participants

Fifteen participants completed the questionnaire. Eight participants generated task metaphors. 5 participants were male, 3 were female, aged from 25 to 58 with a mean age of 38. Seven participant generated performance metaphors. 4 participants were male, 3 were female, aged from 24 to 60 with a mean age of 35. No reward was given for participation in the study.

Results

A total of 104 task metaphors and 84 performance metaphors were generated by participants. Table 5.1 shows the number of unique metaphors proposed for each freehand gesture by participants who completed the *task metaphor* questionnaire. Table 5.2 shows the number of unique metaphors proposed for each freehand gesture by participants who completed the *performance metaphor* questionnaire. In both tables the Gesture Category of the freehand gesture, the most proposed metaphor and the calculated agreement score (see Wobbrock et al. [2009]) are shown.

Table 5.1: Most Proposed Task Metaphors Generated by Participants for Each Freehand Gesture in an Online Questionnaire Presented Alongside the Number of Unique Metaphors Generated and the Agreement Score

Freehand Gesture	**Gesture Category**	**Most Proposed Task Metaphor** (as though you are...)	**No. of Unique Metaphors Generated**	**Agreement Score**
Select	A	point at something	3	0.55
Close	A	closing a book	4	0.39
Open	A	opening a book	4	0.39
Drop	A	letting go of something	5	0.22
Move	A	picking up an object and placing it elsewhere	5	0.22
Pick Up	A	lifting something up	7	0.14
Stop	A	pushing a door in front of you	7	0.14
Move Forward	B	pushing a book along a shelf	5	0.22
Move Back	B	putting something to the left	6	0.17
Zoom In	B	tunnelling into a view	6	0.17
Zoom Out	B	widening a view	6	0.17
Play	C	drawing a circle	4	0.39
Delete	C	drawing the letter X	5	0.22
Search	C	winding clock forward	5	0.20
Turn On	C	turning up the volume on a radio	6	0.18
Go To	C	patting the wall	6	0.17
Show Me	C	parting something	6	0.17
Turn Off	C	turning the volume control on a stereo	7	0.14

Table 5.2: Most Proposed performance metaphor Generated by Participants for Each Freehand Gesture in an Online Questionnaire Presented Alongside the Number of Unique Metaphors Generated and the Agreement Score

Freehand Gesture	**Gesture Category**	**Most Proposed performance metaphor** (looks like you are...)	**No. of Unique Metaphors Generated**	**Agreement Score**
Select	A	pointing in front of you	2	0.78
Stop	A	making the stop sign	3	0.44
Drop	A	you are dropping something	3	0.41
Close	A	turning your hands inwards in a semicircle	4	0.33
Pick Up	A	holding a bag and lifting it upwards	5	0.22
Open	A	turning your hands outward in a semicircle	6	0.19
Move	A	lifting something	6	0.18
Zoom Out	B	drawing the letter V from the bottom to the top	4	0.44
Move Back	B	performing two karate chops	3	0.33
Zoom In	B	drawing the V letter with both hands from top to bottom	4	0.28
Move Forward	B	chopping something once to your left then once in the middle of your body	6	0.18
Play	C	drawing a circle anticlockwise	3	0.59
Delete	C	drawing the letter X	3	0.47
Show Me	C	a shallow V shape	3	0.38
Search	C	drawing the letter Q	4	0.28
Go To	C	signalling to stop and then slide it to your right	6	0.18
Turn On	C	rotating a dial clockwise	6	0.18
Turn Off	C	rotating a dial anti-clockwise	6	0.18

5.1.2 Rating Metaphors Questionnaire

In the second online questionnaire participants were asked to rate each unique *task metaphor* or *performance metaphor* generated for the freehand gestures.

Procedure

Participants were randomly allocated to either a *task metaphor* or a *performance metaphor* condition. Participants were provided with introductory text which explained the purpose of the questionnaire. Under this introductory text was the participant instructions, examples and a practice question. All participants were asked to rate on a scale of 1..10 (where 1 is very bad and 10 is very good) how well the *"description describes how to perform the gesture"*. Participants were provided with six examples which showed a video of a freehand gesture not in our freehand gesture set and an example metaphor.

Following the presentation of instructions, examples and a consent form page, participants were presented with each metaphor along side a video of the freehand gesture it referred to. Participants were asked to rate the metaphor. The order in which the metaphors were presented to participants was randomised. See Appendix C.1.2 for each of the forms presented to participants in this online questionnaire.

Participants

Forty-two participants completed the questionnaire. Twenty-one participants rated the unique task metaphors generated by participants from Questionnaire 1. 12 participants were male, 9 were female, aged from 20 to 47 with a mean age of 33. Twenty-one participants rated the unique performance metaphors generated by participants from Questionnaire 1. 14 participants were male, 7 were female, aged from 22 to 43 with a mean age of 29. No reward was given for participation in the study.

Results

Tables 5.3 and 5.4 show the highest mean rated metaphor for each freehand gesture in Questionnaire 2. Additionally, both tables show the mean rating for the most proposed metaphor from Questionnaire 1.

Interestingly, examining these tables we can see that the most proposed metaphors from Questionnaire 1 are not always the highest rated metaphor in Questionnaire 2. For participants who rated task metaphors in Questionnaire 2, nine of the 18 most proposed metaphors from Questionnaire 1 are also the highest rated metaphors Questionnaire 2. For participants who rated performance metaphors in Questionnaire 2, six of the 18 most proposed metaphors from Questionnaire 1 are also the highest rated metaphors Questionnaire 2.

For participants in the *task metaphor* condition in Questionnaire 2, the mean of the highest rated metaphors is 7.90 (*sd*=1.11). The mean of the highest rated metaphors in Category A was 8.31 (*sd*=0.80), Category B was 7.83 (*sd*=0.77) and Category C was 7.53 (*sd*=1.42).

For participants in the *performance metaphor* condition in Questionnaire 2, the mean of the highest rated metaphors is 7.55 (*sd*=0.95). The mean of the highest rated metaphors in Category A was 7.92 (*sd*=0.48), Category B was 7.34 (*sd*=0.98) and Category C was 7.29 (*sd*=1.16).

Table 5.3: Task Metaphor and Highest Participant Mean Rating from Questionnaire 2 for Each Freehand Gesture. Also Shown is the Participant Mean Rating of the Most Proposed Task Metaphor from Questionnaire 1.

Freehand Gesture	**Gesture Cate-gory**		**Highest Rating Metaphor** (as though you are...)	**Mean Rating**
Select	A	Q2	point at something	8.91
		Q1	point at something	8.91
Close	A	Q2	closing the flaps on top of a large cardboard box	8.73
		Q1	closing a book	5.91
Move	A	Q2	putting a piece of rubbish in the bin	8.73
		Q1	picking up an object and placing it elsewhere	7.05
Pick Up	A	Q2	lifting something up	8.59
		Q1	lifting something up	8.59
Stop	A	Q2	telling someone to not continue where they are going	8.50
		Q1	pushing a door in front of you	6.73
Open	A	Q2	opening the flaps on a large cardboard box	8.09
		Q1	opening a book	5.91
Drop	A	Q2	letting go of something	6.59
		Q1	letting go of something	6.59
Zoom Out	B	Q2	widening a view	8.86
		Q1	widening a view	8.86
Zoom In	B	Q2	tunnelling into a view	8.23
		Q1	tunnelling into a view	8.23
Move Forward	B	Q2	pushing something to the right	7.27
		Q1	pushing a book along a shelf	6.0
Move Back	B	Q2	putting something to the left	6.95
		Q1	putting something to the left	6.95

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Table 5.3 – *Continued from previous page*

Freehand Gesture	**Gesture Category**		**Highest Rating Metaphor** (as though you are...)	**Mean Rating**
Delete	C	Q2	marking something is wrong	9.18
		Q1	drawing the letter X	8.73
Play	C	Q2	winding clock hands forwards	8.95
		Q1	drawing a circle	8.86
Turn Off	C	Q2	turning a door knob	8.55
		Q1	turning the volume control on a stereo	8.18
Turn On	C	Q2	turning a dial	8.18
		Q1	turning up the volume on a radio	7.77
Search	C	Q2	winding a clock backwards	6.45
		Q1	winding a clock backwards	6.45
Go To	C	Q2	patting the wall	5.86
		Q1	patting the wall	5.86
Show Me	C	Q2	parting something	5.55
		Q1	parting something	5.55

Table 5.4: performance metaphor and Highest Participant Mean Rating from Questionnaire 2 for Each Freehand Gesture. Also Shown is the Participant Mean Rating of the Most Proposed performance metaphor from Questionnaire 1.

Freehand Gesture	**Gesture Category**		**Highest Rating Metaphor** (looks like)	**Mean Rating**
Close	A	Q2	turning your hands inwards in a semicircle	7.63
		Q1	turning your hands inwards in a semicircle	7.63
Pick Up	A	Q2	grabbing something and moving it upward	8.37
		Q1	holding a bag and lifting it upwards	7.32
Stop	A	Q2	pushing something away from in front of you	8.26
		Q1	making the stop sign	8.16
Move	A	Q2	picking up something on your left and placing it to your right	8.05
		Q1	lifting something	5.95
Select	A	Q2	you are shooting a gun	7.89
		Q1	pointing in front of you	6.11
Drop	A	Q2	you are dropping something	7.32
		Q1	you are dropping something	7.32

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Table 5.4 – *Continued from previous page*

Freehand Gesture	**Gesture Category**		**Highest Rating Metaphor** (looks like)	**Mean Rating**
Open	A	Q2	turning your hands outward in a semicircle	7.21
		Q1	turning your hands outward in a semicircle	7.21
Zoom Out	B	Q2	drawing the letter V from the bottom to the top	8.05
		Q1	drawing the letter V from the bottom to the top	8.05
Zoom In	B	Q2	drawing the V letter with both hands from top to bottom	7.84
		Q1	drawing the V letter with both hands from top to bottom	7.84
Move Forward	B	Q2	placing your hand at the start of the timeline and jumping to the end	6.84
		Q1	chopping something once to your left then once in the middle of your body	5.0
Move Back	B	Q2	placing your hand at the end of a line and moving it to the start	6.0
		Q1	performing two karate chops	4.58
Delete	C	Q2	drawing the letter X	9.16
		Q1	drawing the letter X	9.16
Play	C	Q2	drawing a circle anticlockwise	7.84
		Q1	drawing a circle anticlockwise	7.84
Search	C	Q2	drawing a number 9	7.63
		Q1	drawing the letter Q	6.37
Turn Off	C	Q2	turning a claw shape to the left	7.42
		Q1	rotating a dial anti-clockwise	6.63
Turn On	C	Q2	turning a claw shape to the right	7.26
		Q1	rotating a dial clockwise	6.95
Go To	C	Q2	you are waving	6.74
		Q1	signalling to stop and then slide it to your right	6.16
Show Me	C	Q2	moving two items with your hands	5.0
		Q1	a shallow V shape	4.58

5.1.3 Discussion

In Chapter 4 Section 4.1 we propose two types of metaphor. A task metaphor which explains the freehand gesture in terms of an example user task. That is, a task, operation or manipulation the user might perform with that freehand gesture on an object. For example, "as though you are spinning an LP" to play a song. Where spatial information is conveyed by a task metaphor this is from the perspective of the user interacting on an object. For example, for the *Turn On* freehand gesture the task metaphor might be "as though you are turning a radio dial" which may be elaborated to include a "clockwise" direction of movement of the dial.

Conversely, a performance metaphor describes the physical shape and movement of the freehand gesture e.g. "looks like drawing the letter O" to play a song. Importantly, performance metaphors describe movements made by the user for example, "looks like a rotating your wrist to the right" to turn on a TV.

The results from Questionnaire 1 show that participants were able to generate suitable task and performance metaphors. That is, participants did generate task metaphors which generally described the operations or manipulations performed on an object. Similarly, participants did generate performance metaphors which generally describe the movements that would be made by a user and in particular from the spatial frame of user.

Examining the ratings of the metaphors in Questionnaire 2, we can see that the most proposed metaphors from Questionnaire 1 are not always the highest rated metaphors. Where the highest rated task metaphor is different to the most proposed task metaphor, the difference for freehand gestures in Category A is the task it describes (e.g. from "opening a book" to "opening the flaps on a large cardboard box"), for Category B the addition of a direction of movement of the object (e.g. from "pushing a book along a shelf" to "pushing something to the right") and for Category C a change in the task described (e.g. from "turning the volume control on a stereo" to "turning a door knob") and either the addition or removal of a direction of movement (e.g. from "drawing a circle" to "winding clock hands forward" or from "turning up the volume on a radio" to "turning a dial").

Where the highest rated performance metaphor is different to the most proposed performance metaphor, the difference for freehand gestures in Category A, B and C is an elaboration or change in the movement performed by the user as described by the metaphor (e.g. from "lifting something" to "picking something up on your left and placing it on your right" or from "performing two karate chops" to "placing your hand at the end of a line and moving it to the start"). Additionally, for some freehand gestures in Category C this difference also includes a change in the shape of the hands (e.g. from "rotating a dial anti-clockwise" to "turning a claw shape to the left").

Furthermore, the results from Chapter 4 examining the fit between the freehand gesture and the task and how participants reported remembering the freehand gestures, indicated that from a user/participant perspective 1. a task metaphor better supported the learning of freehand gestures from Category A and 2. a performance metaphor better supported the learning of freehand gestures from Category B and C.

This latter result, i.e. the importance of directional information either when acting on an object or made by the user, is also suggested in the results of the rating of task and performance metaphors in Questionnaire 2. That is, for freehand gestures in Category B and C participants rate more highly task metaphors which better indicate the direction of movement of the object and performance metaphors which better reflect the direction of the movements made by the user when performing the freehand gesture.

To select the task and performance metaphors used in the following studies, we select those metaphors from Questionnaire 2 with the highest mean rating. We adopt this approach so as to select the most suitable metaphor for each freehand gesture.

Furthermore, the results from Questionnaire 2 enable the comparison of selected metaphors. This addresses the potential limitation highlighted in Chapter 4 that, there was no way of measuring if each metaphor was equally suitable. For example, was the task metaphor for *Open* equally as suitable as the performance metaphor for *Open*?

The results from Questionnaire 2 provide this information. Examining the mean ratings of the highest rated task metaphors and performance metaphor for each freehand gesture shows that they are perceived as equally well suited to explaining/describing how to perform the freehand gesture. Table 5.5 shows both the task metaphors and performance metaphors selected for use in the subsequent study.

Table 5.5: Task Metaphor and performance metaphors Selected from Questionnaire 2 for each Freehand Gesture

Freehand Gesture	**Gesture Category**	**Task Metaphor** (as though you are...)	**performance metaphor** (looks like...)
Close	A	closing the flaps on top of a large cardboard box	turning your hands inwards in a semicircle
Drop	A	letting go of something	you are dropping something
Move	A	putting a piece of rubbish in the bin	picking up something on your left and placing it to your right
Open		A opening the flaps on a large cardboard box	turning your hands outward in a semicircle
Pick Up	A	lifting something up	grabbing something and moving it upward
Select	A	point at something	you are shooting a gun
Stop	A	telling someone to not continue where they are going	pushing something away from in front of you
Move Back	B	putting something to the left	placing your hand at the end of a line and moving it to the start
Move Forward	B	pushing something to the right	placing your hand at the start of the timeline and jumping to the end
Zoom In	B	tunnelling into a view	drawing the V letter with both hands from top to bottom
Zoom Out	B	widening a view	drawing the letter V from the bottom to the top
Delete	C	marking something is wrong	drawing the letter X
Go To	C	patting the wall	you are waving
Play	C	winding clock hands forwards	drawing a circle anticlockwise
Search	C	winding a clock backwards	drawing a number 9
Show Me	C	parting something	moving two items with your hands
Turn On	C	turning a door knob	turning a claw shape to the right
Turn Off	C	turning an dial	turning a claw shape to the left

5.2 Study I: Prompted Transfer of Learning

In this study we examine the transfer of learning of freehand gestures and experimentally test the observation made in the literature that there are advantages to supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction), on the transfer of learning of freehand gestures.

The study presented consists of two phases - *Training Phase* and *Transfer of Learning Phase*. The *Training Phase* consists of 2 sessions. In session 1 participants are trained on the freehand gesture set generated in Chapter 3. Participants are trained on the freehand gestures with reference to an example user task e.g. "to stop a video...". Participants are then sent away and asked to return after 7 days to complete session 2. In session 2, participants are tested, and if required, retrained so as to be able to correctly remember and accurately perform each freehand gesture for the corresponding user task. Participants are again sent away and asked to return after 7 days to complete the *Transfer of Learning Phase* of the study.

The *Transfer of Learning Phase* again, consists of 2 sessions. In both sessions 3 and 4, participants are read aloud a new set of user tasks and asked to perform the freehand gesture, from those they have been trained on, which they feel would best perform that user task. For each freehand gesture, two new user tasks are presented; a *Directed* user task which contains the same verb for the freehand gesture as presented in the training user task e.g. "to stop recording" and an *Open Ended* user task which uses a synonym of the verb for the freehand gesture presented in the training user task e.g. "to finish listening to a podcast".

Transfer of learning is assessed to have occurred, from a designers/experimenters perspective, if participants perform the freehand gesture sought for prior to the study by the experimenter. Additionally, participant perception of the suitability of the performed freehand gesture for the new user task is used to assess transfer of learning from a user/participant perspective.

In designing the study, Barnett and Ceci [2002] taxonomy is used to identify and control, as far as possible, the factors which might influence transfer of learning. Barnett and Ceci's taxonomy proposes a number of dimensions along which studies can be organised. These dimensions are divided into two overall factors -content (i.e. what is transferred) and context (i.e. when and where content is transferred from and to).

Content is further divided into three dimensions - learned skill, performance change and memory demands. In this study participants are told to use the freehand gestures which they have been taught to perform new user tasks (learned skill). We suggest this study examines *near* transfer of learning as participants are prompted into performing previously learnt freehand gestures for new user tasks. Transfer of learning is assessed to have occurred if the participant performs the freehand gesture sought for by the experimenter prior to the study for each new user task presented (performance change). In introducing *Directed* and *Open Ended* user tasks we alter the memory demands to further examine transfer of learning of freehand gestures. *Directed* user tasks invite an automatic performance of the corresponding freehand gesture as the new user task in broadly similar to the user task presented during training. *Open Ended* user tasks seek to examine transfer of learning for dissimilar user tasks where the participant has to think about which taught freehand gesture best performs this unfamiliar user task.

Context is again further divided into six dimensions - knowledge domain, physical context, temporal context, functional context, social context and modality. In this study all participants are told to use the freehand gestures which they have been taught to perform new user tasks (knowledge domain). Participants complete the study, individually, as part of a laboratory experiment (physical, functional and social context). The study is conducted over 4 weeks, 2 of which assess transfer of learning (temporal context). Finally, transfer of learning is assessed by presenting participants with new user tasks and examining if the participant performs the freehand gesture which the designer/experimenter states prior to the study (modality). Additionally, transfer of learning is assessed, from a user/participant perspective, by examining the participants perceptions of the suitability of the freehand gestures they perform (modality).

5.2.1 Method

Design

A three factor mixed experimental design was followed. The independent measure was the metaphor presented to the participants. The repeated measures were the Gesture Category and Task Type presented to participants.

The independent measure independent variable was the explanation of the metaphor during training, with three levels (*task metaphor, performance metaphor* or *no metaphor* given). The repeated measures independent variables were 1. the Gesture Category of the freehand gesture with three levels (A, B and C) and 2. Task Type presented with two levels (Directed and Open Ended).

Our primary dependent variable is the selection of an appropriate freehand gesture, measured as the participant choosing the freehand gesture sought for by the experimenter for the new user task.

All participants were asked to rate their familiarity with each freehand gesture on a scale of 1..7 (where 1 is not familiar and 7 very familiar). This is, prior to entering the study had the participant encountered or used this freehand gesture before. All participants were asked to give details of this familiarity.

The final dependent variable was the participants perception of the fit between the freehand gesture and the task. This was measured by rating on a scale of 1..7 (where 1 is not well matched and 7 very well matched) in response to the question, *"how well the well do you think* *the gesture matched the task"* (i.e. the suitability of the freehand gesture for the given user task).

Hypotheses

This study examines (i) if transfer of learning of freehand gestures does occur and (ii) if by supporting both mechanisms of transfer of learning, participants are better able to transfer learnt freehand gestures to new user tasks.

Does Transfer of Learning of Freehand Gesture Occur?

As highlighted in the literature (e.g. Royer [1979]; Salomon and Perkins [1989]; Tuomi-Grohn and Engestrom [2003]) there are many different factors which potentially influence transfer of learning. To address this challenge we utilise Barnett and Ceci [2002] taxonomy to identify and control, as far as possible, the factors which might influence transfer of learning. In designing the study we chose to alter the memory demands factor in Barnett and Ceci taxonomy and as far as possible keep all other factors constant. To alter the memory demands factor we present participants with *Directed* and *Open Ended* user tasks, asking participants to perform the freehand gesture, from those they have been trained on, which they feel best performs the new task.

To examine if transfer of learning occurs we hypothesis that,

H1: More freehand gestures sought for by the experimenter, will be performed by participants for new user tasks than other taught freehand gestures

Furthermore, the literature suggests that transfer of learning will occur more for situations which are more similar to that in which the original knowledge was taught (e.g., Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). Therefore, we hypothesis that,

H2: More transfer of learning will be observed for Directed user tasks than Open Ended user tasks

The Effect of Supporting Both Mechanisms of Transfer of Learning

Building on the literature, specifically the observation that supporting both mechanisms of transfer of learning has a positive effect on transfer of learning, we hypothesis that a metaphor, introduced during participant training, will support the transfer of learning of freehand gestures,

H3: The use of metaphor in training will improve participants transfer of learning of freehand gestures

Furthermore, two types of metaphor are used (i) a *task metaphor* explains the freehand gesture in terms of an example user task or (ii) a *performance metaphor* which describes the physical shape and movement of the freehand gesture. To better understand which type of metaphor better supports transfer of learning of freehand gestures we hypothesised that,

H4: There will be a difference between the effects of task metaphors and performance metaphors on participants transfer of learning of freehand gestures

Participants

Eighteen participants took part in the study, aged from 19 to 48 with a mean age of 28. 13 participants were male and 5 were female. All participants were right-handed. All participants were recruited from around the University of Bath. Participants were entered into a prize draw to win an Amazon Kindle Fire HD as remuneration for their time.

Procedure

Participants were run individually and randomly allocated to a metaphor experimental condition - *task metaphor, performance metaphor* or *no metaphor* given. The study had two phases - *Training Phase* and *Transfer of Learning Phase*, consisting of 4 sessions in total: two training sessions and two transfer of learning sessions.

Training Phase - Training : Session 1

Participants were trained on the freehand gesture set from Chapter 3. Depending on the randomly allocated condition, each participant was shown a scripted video of each freehand gesture. In all conditions the video first presents an example user task for the freehand gesture (see Table 5.6). In the *task metaphor* and *performance metaphor* conditions the video then presents the metaphor for the freehand gesture. Finally, in all conditions, the video presents a verbal description of the freehand gesture followed by a demonstration.

After watching the video for each freehand gesture, the participant was asked to perform that freehand gesture correctly 10 consecutive times to the experimenter. If an error was made, it was recorded; the participant was shown the video again and asked to perform the freehand gesture correctly 10 consecutive times. This procedure was repeated until the participant correctly performed the freehand gesture 10 consecutive times.

An error was recorded if the experimenter assessed that the performance of the freehand gesture was not the same as demonstrated in the scripted videos. That is, not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement.

After correctly repeating a freehand gesture to the experimenter, all participants were asked to rate their familiarity with the freehand gesture prior to starting the study, from where they were familiar with the freehand gesture and how well they thought the freehand gesture matched the task.

Participants were then sent away and asked to return after 7 days to complete the *Training Phase - Recall and Retrain* session of the study. During the intervening period no further training on the metaphor, freehand gestures or user tasks was given.

Training Phase - Recall and Retrain : Session 2

In the *Training Phase - Recall and Retrain* session, participants were asked to correctly remember and perform the freehand gestures they had been trained on. Participants were run individually. The experimenter read aloud a user task and the participant was asked to perform the corresponding freehand gesture. The order of the freehand gestures was randomised for each participant (i.e. not in the same order in which they had been trained).

If the participant forgot the freehand gesture or performed the freehand gesture incorrectly, the scripted video describing the metaphor (if one was provided) was played. If the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the scripted video describing the freehand gesture was played. Finally, if the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the video demonstration of the freehand gesture being performed was played. At each stage, if the participant performed the freehand gesture correctly the experimenter moved on to the next freehand gesture. All errors were recorded.

Participants who were able to correctly remember and perform each freehand gesture in five or less recall and retrain assessments were invited to return after 7 and 14 days to complete the *Transfer of Learning Phase* of the study. During the intervening period no further training on the metaphor, freehand gestures or user tasks was given.

Transfer of Learning Phase : Sessions 3 and 4

In the *Transfer of Learning Phase* participants were read aloud a new set of user tasks (see Tables 5.7 and 5.8) and asked to perform, from those freehand gestures they had learnt in the *Training Phase*, the most suitable freehand gesture to perform that user task. New user tasks were either *Directed* i.e. contained the same verb for the freehand gesture as presented in the training user task (e.g. “to stop a video” and “to stop recording”) or *Open Ended* i.e. used a synonym of the verb for the freehand gesture presented in the training user task (e.g. “to stop a video” and “to finish listening to a podcast”). The order in which the new set of user tasks were read aloud was randomised.

Participants received no feedback on the 'correctness' of the freehand gesture. Freehand gestures made by participants were recorded by the experimenter. After the participant had performed a freehand gesture they were asked to rate how well they thought the freehand gesture matched the task.

Table 5.6: The Example User Tasks Used to Train Participants on each Freehand Gesture in Study I and Study II

Freehand Gesture	**Gesture Category**	**User Task**
Close	A	To close an application...
Drop	A	To drop a photo into a collection...
Move	A	To move an icon...
Open	A	To open a web browser...
Pick Up	A	To pick up a document...
Select	A	To select a file...
Stop	A	To stop a video...
Move Back	B	To move back a page...
Move Forward	B	To move forward in a playlist...
Zoom In	B	To zoom in on a display...
Zoom Out	B	To zoom out of a map...
Delete	C	To delete a spreadsheet...
Go To	C	To go to your media...
Play	C	To play a song...
Search	C	To search for a diary contact...
Show Me	C	To show me more information...
Turn Off	C	To turn off the computer...
Turn On	C	To turn on a printer...

Table 5.7: The New Set of User Tasks Used in the *Transfer of Learning Phase* session 3 of Both Study I and Study II

Freehand Gesture	**Gesture Category**	**Directed User Task**	**Open Ended User Task**
Close	A	To close the blinds...	To finish using an app...
Drop	A	To drop an item into a to-do-list...	To leave a reminder at this location...
Move	A	To move an image onto your mobile...	To put a video from your laptop onto the TV...
Open	A	To open the Electronic Program Guide...	To begin reading a book...
Pick Up	A	To pick up the video message...	To collect a message...
Select	A	To select an audio book...	To choose a movie...
Stop	A	To stop recording...	To finish listening to a podcast...
Move Back	B	To move back to the previous TV channel...	To go back to the previous chapter...
Move Forward	B	To move forward to the next song...	To skip to the next image...
Zoom In	B	To zoom in on a photograph...	To enlarge a feature in a photo...
Zoom Out	B	To zoom out of an image...	To shrink a feature in on a display...
Delete	C	To delete a reminder...	To remove a note...
Go To	C	To go to your shopping list...	To view to your video collection...
Play	C	To play a movie...	To start listening to a song...
Search	C	To search for a TV show...	To find a photograph...
Show Me	C	To show me a film review...	To display more details...
Turn Off	C	To turn off the heating...	To switch off the air conditioning...
Turn On	C	To turn on the lights...	To switch on the stereo...

Table 5.8: The New Set of User Tasks Used in the *Transfer of Learning Phase* session 4 of Both Study I and Study II

Freehand Gesture	**Gesture Category**	**Directed User Task**	**Open Ended User Task**
Close	A	To close the advertisement...	To shut the doors...
Drop	A	To drop a marker...	To leave a comment...
Move	A	To move an appointment...	To transfer a coupon...
Open	A	To open your travel planner...	To launch an app...
Pick Up	A	To pick up your tickets...	To take a menu...
Select	A	To select a review...	To highlight a shop...
Stop	A	To stop the audio guide...	To end all notifications...
Move Back	B	To move back to the start...	To go back to the previous announcement...
Move Forward	B	To move forward in a list...	To jump to the next translation...
Zoom In	B	To zoom in on a route map...	To make bigger the small print...
Zoom Out	B	To zoom out of a photo...	To make smaller an image...
Delete	C	To delete a booking...	To erase a phone number...
Go To	C	To go to your contacts...	To view your travel plans...
Play	C	To play your music...	To start the video stream...
Search	C	To search for a cafe...	To find a car park...
Show Me	C	To show me my location...	To display all reservations...
Turn Off	C	To turn off traffic alerts...	To switch off your mobile...
Turn On	C	To turn on location tracking...	To switch on sat nav...

5.2.2 Results

We present the results of this study broken down into three parts. In the first part we present the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

In the second part we present the results examining the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a designers/experimenters perspective, reporting the results examining the effect of metaphor, introduced during participant training, on the transfer of learning of freehand gesture (H3). We also examine which type of metaphor better supports transfer of learning of freehand gestures (H4).

In the third part we examine transfer of learning of freehand gestures from a user/participant perspective. We present the results examining participant ratings of the suitability of freehand gestures both when freehand gestures are transferred as desired by the designer/experimenter as well as when taught freehand gestures are performed (H3 and H4).

Does Transfer of Learning of Freehand Gesture Occur?

In this section we report the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2). To examine if transfer of learning occurs we hypothesis that *more freehand gestures sought for by the experimenter, will be performed by participants for new user tasks than other taught freehand gestures*.

The results show that all participants performed a sought for freehand gesture for 70% of new user tasks (both *Directed* or *Open Ended*). Overall, this suggests that we can confirm our hypothesis (H1).

Furthermore, the results show that participants in the *task metaphor* condition performed a sought for freehand gesture for 69% of new user tasks (both *Directed* or *Open Ended*). Similarly, participants in the *performance metaphor* condition performed a sought for freehand gesture for 74% of new user tasks. Finally, participants in the *no metaphor* condition performed a sought for freehand gesture for 69% of new user tasks.

Additionally, we hypothesis that *more transfer of learning will be observed for Directed user tasks than Open Ended user tasks* (H2). All participants performed a sought for freehand gesture for 76% of new *Directed* tasks and for 65% of new *Open Ended* tasks. A one-way ANOVA indicates that difference is significant ($F=18.713$, $p<0.001$) and suggests that we can confirm our hypothesis (H2).

Furthermore, the results show that participants in the *task metaphor* condition performed a sought for freehand gesture for 76% of new *Directed* tasks and for 61% of new *Open Ended* tasks. Participants in the *performance metaphor* condition performed a sought for freehand gesture for 80% of new *Directed* tasks and for 56% of new *Open Ended* tasks. Finally, participants in the *no metaphor* condition performed a sought for freehand gesture for 78% of new *Directed* tasks and for 61% of new *Open Ended* tasks.

Designers/Experimenters Perspective - Sought For Transfer of Learning of Freehand Gestures

This section reports the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a designers/experimenters perspective. This is, for each new user task presented to participants in both sessions of the *Transfer of Learning Phase*, the designer/experimenter stated which freehand gesture should be used. Successful transfer of learning from a designer/experimenter perspective is the transfer of a specific freehand gesture to the new user task (H3). The results reported also examine which type of metaphor better supports transfer of learning of freehand gestures (H4).

A four-way mixed ANOVA was conducted, with three repeated measures (Session, Task Type and Gesture Category) and one independent measure (metaphor condition). Session refers to the two sessions of the *Transfer of Learning Phase*. Task Type refers to either a *Directed* or *Open Ended* user task presented to participants.

The results report a main effect of metaphor condition (F=5.576, p=0.019). Post hoc Tukey tests indicate that participants in the *performance metaphor* condition transfer more sought for freehand gestures than participants in the *no metaphor* condition (p=0.016). There was no such significant difference between participants in the *performance metaphor* and *task metaphor* conditions (p=0.135) or between participants in the *task metaphor* and *no metaphor* conditions (p=0.338).

There was also a main effect of Task Type (F=31.314, $p<0.001$) with contrasts revealing that more sought for transfer of learning of freehand gestures occurred for *Directed* tasks (m=16.561, sd=0.328) than *Open Ended* tasks (m=13.332, sd=0.650).

There was an interaction effect between Task Type and Gesture Category (F=11.523, $p<0.001$). Contrasts reveal that, between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the sought for transfer of learning of freehand gestures between Category A and Category C (F=16.90, p=0.001) as well as between Category B and Category C (F=17.463, p=0.001). There was no such difference between Category A and Category B (F=0.90, p=0.362).

Examination of the means indicates that for *Directed* tasks all participants transfer more sought for freehand gestures in Category A (m=16.57, sd=0.60) and Category B (m=18.68, sd=0.74) than in Category C (m=14.44, sd=0.75). However, for *Open Ended* tasks all participants transfer more sought for freehand gestures in Category C (*m*=13.96, *sd*=0.81) than in Category A (*m*=12.46, *sd*=0.76) or Category B (*m*=13.59, *sd*=1.13).

Finally, there was an interaction effect between Session and Gesture Category (F=3.752, p=0.038). Contrasts reveal that, between *Session 3* and *4*, there is a statistically significant difference in the sought for transfer of learning of freehand gestures between Category B and Category C (F=5.489, p=0.037). There was no such difference between Category A and Category B (F=3.190, p=0.099) as well as Category A and Category C (F=1.438, p=0.254).

Examination of the means indicates that all participants transfer more sought for freehand gestures in Category B in *Session 3* (*m*=16.94, *sd*=0.83) than *Session 4* (*m*=15.32, *sd*=0.93). Whereas, participants transfer more sought for freehand gestures in Category C in *Session 4* (*m*=14.82, *sd*=0.72) than *Session 3* (*m*=13.57, *sd*=0.89).

User/Participant Perspective - Participant Rating of Transferred Freehand Gestures

This section reports the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a user/participant perspective. That is we examine the participant rating of the fit between the freehand gesture and the task for each freehand gesture performed in response to a new user task (H3 and H4). First we examine if there is a difference in this rating between the metaphor conditions regardless of whether participants performed the sought for freehand gesture. Next we examine this difference when participants performed the sought for freehand gesture and when they performed another taught freehand gesture. Finally, we examine if there is a correlation between the rating of the fit between the freehand gesture and the task and the number of sought for transfer of learning of freehand gestures.

Participant Rating of Performed Freehand Gestures

This section examines participant rating of the fit between the freehand gesture and the task when they perform any freehand gesture in response to a new user task. In examining this relationship we examine if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures even if these might not be the freehand gesture sought for by the designer/experimenter.

A four-way mixed ANOVA was conducted, with three repeated measures (Session, Task Type and Gesture Category) and one independent measure (metaphor condition). Session refers to the two sessions of the *Transfer of Learning Phase*. Task Type refers to either a *Directed* or *Open Ended* user task presented to participants.

The results report no main effect of metaphor condition (F=2.895, p=0.094). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=5.43, *sd*=0.37) and *performance metaphor* condition (*m*=5.33, *sd*=0.34) rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition (*m*=4.22, *sd*=0.41).

There was a main effect of Session (F=5.847, p=0.032) . Contrast revel than all participants rate the fit between the freehand gesture and the task higher in *Session 4* (*m*=5.05, *sd*=0.21) than in *Session 3* (*m*=4.93, *sd*=0.23).

There was a main effect of Task Type (F=20.673, p=0.001). Contrasts reveal that all participants rate the fit between the freehand gesture and the task higher for *Directed* tasks (*m*=5.07, *sd*=0.23) than *Open Ended* tasks (*m*=4.91, *sd*=0.21).

There was a main effect of Gesture Category (F=20.731, p$<$0.001). Contrasts revel than for all participants the is a statistically significant different in the rating the fit between the freehand gesture and the task between Category A and Category B (F=10.949, p=0.006), Category A and Category C (F=11.368, p=0.006) and Category B and C (F=36.276, p$<$0.001). Examining the means shows that all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B (*m*=5.28, *sd*=0.21), than Category A (*m*=5.0, *sd*=0.22), which was rated higher than Category C (*m*=4.69, *sd*=0.24).

Finally, there was an interaction effect between Task Type and Gesture Category (F=11.247, p=0.001). Contrasts reveal that between *Directed* and *Open Ended* tasks there is a statistically significant difference in the rating of fit between the freehand gesture and the task, between freehand gestures in Category A and Category C (F=29.258, p$<$0.001) as well as between Category B and Category C (F=8.118, p=0.015). There was no such different between Category A and Category B (F=2.804, p=0.120).

Examination of the means indicates that for *Directed* tasks all participants rate the fit between the freehand gesture and the task, higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B (*m*=5.38, *sd*=0.23) than Category A (*m*=5.16, *sd*=0.23) which are rated higher than Category C (*m*=4.68, *sd*=0.25). For *Open Ended* tasks all participants rate the fit between the freehand gesture and the task when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category A (*m*=4.84, *sd*=0.21) or Category B (*m*=5.19, *sd*=0.21) lower than for *Directed* tasks. However, for freehand gestures in Category C (*m*=4.70, *sd*=0.23) participants rate the fit between the freehand gesture and the task similarly to *Directed* tasks.

Participant Rating when the Sought For Freehand Gesture is Performed

This section examines the effect of metaphor, introduced during participant training, on participant ratings of the fit between the freehand gesture and the task when they perform the freehand gesture sought for by the designer/experimenter.

A four-way mixed ANOVA reports no main effect of metaphor condition (F=3.270, p=0.074). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=5.74, *sd*=0.39) and the *performance metaphor* condition (*m*=5.64, *sd*=0.35) rate the fit between the freehand gesture and the task higher when performing a sought for freehand gesture in response to a new user task than participants in the *no metaphor* condition (*m*=4.41, *sd*=0.43).

There was a main effect of Session (F=7.248, p=0.02) . Contrast revel than all participants rate the fit between the freehand gesture and the task higher when performing a sought for freehand gesture in response to a new user task in *Session 4* (*m*=5.36, *sd*=0.22) than in *Session 3* (*m*=5.19, *sd*=0.23).

There was also a main effect of Task Type (F=5.202, p=0.042). Contrasts reveal that all participants rate the fit between the freehand gesture and the task higher when performing a sought for freehand gesture for *Directed* tasks (*m*=5.32, *sd*=0.23) compared to *Open Ended* tasks (*m*=5.20, *sd*=0.21).

Finally, there was an interaction effect between Task Type and Gesture Category (F=6.320, p=0.007). Contrasts reveal that, between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the rating of fit between the freehand gesture and the task when performing a sought for freehand gesture in response to a new user task between Category A and Category C (F=9.930, p=0.008) as well as between Category B and Category C (F=5.103, p=0.043). There was no such difference between Category A and Category B (F=2.354, p=0.151).

Examination of the means indicates that for *Directed* tasks all participants rate the fit between the freehand gesture and the task, when performing a sought for freehand gesture in response to a new user task, higher for Category A (*m*=5.48, *sd*=0.24) and Category B (*m*=5.43, *sd*=0.24) than Category C (*m*=5.06, *sd*=0.30). However, for *Open Ended* tasks all participants rate the fit between the freehand gesture and the task similarly across Category A (*m*=5.17, *sd*=0.21), Category B (*m*=5.29, *sd*=0.19) and Category C (*m*=5.14, *sd*=0.26).

Participant Rating when a Taught Freehand Gesture is Performed

This section examines participant rating of the fit between the freehand gesture and the task when they perform a taught freehand gesture in response to a new user task. We examine if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures when the performed freehand gesture is not the freehand gesture sought for by the designer/experimenter.

A four-way mixed ANOVA reports no main effect of metaphor condition (F=1.628, p=0.237). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition rate the fit between the freehand gesture and the task higher when performing a taught freehand gesture in response to a new user task (*m*=5.07, *sd*=0.36), than participants in the *performance metaphor* condition (*m*=4.58, *sd*=0.32) and the *no metaphor* condition (*m*=4.11, *sd*=0.40).

There was a main effect of Gesture Category (F=5.415, p=0.019). Contrast revel than all participants rate the fit between the freehand gesture and the task higher when performing a taught freehand gesture in response to a new user task for freehand gestures in Category B compared to freehand gestures in Category C (F=20.767, p=0.001).

There was an interaction effect between Session and Gesture Category (F=6.810, p=0.011). Contrasts reveal that between *Session 3* and *Session 4*, there is a statistically significant difference in the rating of fit between the freehand gesture and the task when performing a taught freehand gesture in response to a new user task, between Category A and Category B (F=4.710, p=0.050) as well as between Category B and Category C (F=9.683, p=0.009). There was no such difference between Category A and Category C (F=3.608, p=0.082).

Examination of the means indicates that, all participants rate the fit between the freehand gesture and the task when performing a taught freehand gesture in response to a new user task, higher in *Session 4* where the sought for freehand gesture was from Category A and Category C (*m*=4.74, *sd*=0.31 and *m*=4.55, *sd*=0.22 respectively) than in *Session 3* (*m*=4.42, *sd*=0.31 and *m*=3.97, *sd*=0.28 respectively). However, where the sought for freehand gesture was from Category B, all participants rate the fit between the freehand gesture and the task higher in *Session 3* (*m*=5.03, *sd*=0.89) than in *Session 4* (*m*=4.81, *sd*=0.21).

Finally, there was an interaction effect between Task Type and Gesture Category (F=5.365, p=0.015). Contrasts reveal that, between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the rating of fit between the freehand gesture and the task when performing a taught freehand gesture in response to a new user task, between Category A and Category B (F=11.045, p=0.006) as well as between Category A and Category C (F=4.981, p=0.045). There was no such difference between Category B and Category C (F=0.245, p=0.629).

Examination of the means indicates that for *Directed* tasks all participants rate the fit between the freehand gesture and the task, when performing a taught freehand gesture in response to a new user task, higher where the sought for freehand gesture was from Category A (*m*=4.81, *sd*=0.27), than Category B (*m*=4.77, *sd*=0.17), which were rated higher than Category C (*m*=4.17, *sd*=0.24). However, for *Open Ended* tasks all participants rate the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category B (*m*=5.07, *sd*=0.23), than Category A (*m*=4.35, *sd*=0.34) or Category C (*m*=4.35, *sd*=0.25).

Correlation Between Suitability and Sought For Transfer of Learning

A Pearson product-moment correlation showed that as the rating of the fit between the freehand gesture and the task increases the number of sought for freehand gestures transferred to new user tasks also increases ($r(68)=0.245$, $p=0.044$). This results suggest that, as well as indicating ease of learning, participant perception of the suitability of freehand gestures also indicates the transfer of learning of sought for freehand gestures for new user tasks.

5.2.3 Discussion

In this section we discuss the results examining if transfer of learning of freehand gestures occurred as well as the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. In the first part we discuss the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

In the second part we discuss the results examining the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a designers/experimenters perspective examining the effect of metaphor, introduced during participant training, on the transfer of learning of freehand gesture (H3). We also examine which type of metaphor better supports transfer of learning of freehand gestures (H4).

In the third part we examine transfer of learning of freehand gestures from a user/participant perspective. We discuss the results examining participant ratings of the suitability of freehand gestures performed in response to new user tasks (H3 and H4).

Does Transfer of Learning of Freehand Gesture Occur?

In this section we discuss the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

Firstly, we hypothesised that, *more freehand gestures sought for by the designer/experimenter, will be performed by participants for new user tasks than other taught freehand gestures* (H1). The results report that, all participants performed a sought for freehand gesture for 70% of new user tasks. This suggests that we can confirm our hypothesis (H1).

Secondly, the literature suggests that transfer of learning will more likely to occur for situations which are similar to that in which the original knowledge was taught (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). Therefore, we hypothesised that *more transfer of learning will be observed for Directed tasks than Open Ended tasks* (H2). The results report that, all participants performed a sought for freehand gesture for 76% of new *Directed* tasks and for 65% of new *Open Ended* tasks with a one-way ANOVA indicating that this difference was statistically significant. This suggests that we can confirm our hypothesis (H2).

Overall, these results suggest that we can be confident that transfer of learning of freehand gestures in this study does occur. That is, when told to use only the freehand gestures they had been trained on to perform new user tasks, the majority of the freehand gestures performed by participants were those sought for by the designer/experimenter.

Examining these results further indicates that participants in the *performance metaphor* condition transfer sought for freehand gestures (74%) more than participants in the *task metaphor* condition (69%) and the *no metaphor* condition (69%). These results suggest that supporting both mechanisms of transfer of learning does support the transfer of learning of freehand gestures. That is, participants presented with a performance metaphor transfer more sought for freehand gestures than participants presented with a task metaphor or when no metaphor is presented. Interestingly, the results indicate that the introduction of a task metaphor is no more effective than when no metaphor is introduced during training. This might suggest that training participants with reference to a user task is as good as introducing a task metaphor during training.

Furthermore, the results show that for *Directed* tasks, participants in the *performance metaphor* condition transfer more sought for freehand gestures (80%) than participants in the *task metaphor* condition (76%) and *no metaphor* condition (78%). For *Open Ended* tasks however, participants in the *task metaphor* condition (61%) and *no metaphor* condition (61%) transfer more sought for freehand gestures than participants in the *performance metaphor* condition (56%).

These results suggest that when a new user task is similar to that used in training i.e. a *Directed* task, a performance metaphor better supports transfer of learning. This might suggest that when freehand gestures are to be used across similar devices and applications, training new users on freehand gestures with the introduction of a performance metaphor might better support transfer of learning.

Conversely, when new user task is dissimilar that used in training i.e. a *Open Ended* task, a task metaphor, or simply training participants on the freehand gesture with reference to the user task, better supports transfer of learning. This might suggest that where the devices or application are dissimilar, or potentially unknown, training new users on freehand gestures with the introduction of a task metaphor or no metaphor during training, can better support transfer of learning.

Designers/Experimenters Perspective - Sought For Transfer of Learning of Freehand Gestures

In this section we discuss the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a designers/experimenters perspective. Successful transfer of learning from a designer/experimenter perspective is the transfer of a specific freehand gesture to the new user task (H3). We also discuss which type of metaphor better supports transfer of learning of freehand gestures (H4).

The results indicate that participants in the *performance metaphor* condition transferred more sought for freehand gestures than participants in the *no metaphor* condition. There was no such significant difference between participants in the *task metaphor* condition and *no metaphor* condition. This results suggests that we can confirm our hypothesis H3.

Moreover, this results suggest that we can confirm our hypothesis H4. That is, when told to use only freehand gestures they had been trained on, a performance metaphor better supports participants when transferring learnt freehand gestures to analogous tasks as sought for by the designer/experimenter.

Furthermore, the results also indicate that more sought for transfer of learning occurs for *Directed* tasks compared to *Open Ended* tasks. This result helps to further confirm our hypothesis H2 that *"more transfer of learning will be observed for Directed user tasks than Open Ended user tasks"*.

The results also report an interaction effect between Task Type and Gesture Category. For *Directed* tasks, all participants transfer more sought for freehand gestures from Category A and Category B than from Category C. Whereas, for *Open Ended* tasks, all participants transfer more sought for freehand gestures from Category C than from Category A and Category B.

This might suggest that for *near* transfer of learning i.e. *Directed* tasks, freehand gestures from Category A and Category B are more readily transferred than freehand gestures from Category C. This result is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1906]; Salomon and Perkins [1989]). In this case, new *Directed* user tasks are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A and B are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for *far* transfer of learning i.e. *Open Ended* tasks, freehand gestures from Category C are more readily transferred than freehand gestures from Category A and B. This might suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category A and B.

This latter observation is also suggested by the interaction effect between Session and Gesture Category. The results report that freehand gestures from Category A are transferred similarly between *Session 3* and *Session 4*. That is, both 7 days and 14 days after completion of training, participants transfer similar numbers of sought for freehand gestures from Category A to new user tasks. In contrast, more sought for freehand gestures from Category C are transferred in *Session 4* than in *Session 3*. That is, 14 days after completion of training participants transfer more sought for freehand gestures from Category C than 7 days after completion of training. This might suggest that freehand gestures from Category A are triggered automatically for new user tasks whereas, freehand gestures in Category C are learnt more mindfully and with more exposure to new users tasks participants are able to apply this new knowledge to new situations.

However, the results report that more sought for freehand gestures from Category B are transferred in *Session 3* than in *Session 4*. That is, 14 days after completion of training participants transfer less sought for freehand gestures from Category B than 7 days after completion of training. This suggests that freehand gesture from Category B are not as easily learnt (specifically, producing fewer errors in retention) as freehand gesture in Category A and so are not triggered as automatically for new user tasks. Similarly, these results suggest that freehand gesture from Category B are not as mindfully learnt as freehand gestures in Category C.

These results suggest that the transfer of learning of freehand gesture from Category B is problematic. That is these results might suggest that the transfer of learning of freehand gestures is problematic where the direction and orientation of the hands is a key feature of the freehand gesture i.e. mime gestures where the spatial cognition or spatial frame of the participants who generated the freehand gesture is different to that of the new user. To address this challenge, further support might be provided to new users such as additional training to support learning to automaticity including training on multiple examples of different user tasks to support mindful abstraction. Another solution might be to allow new user to choose the direction and orientation of the hands for these freehand gestures to better support a new users perception of the suitability of the freehand gesture.

User/Participant Perspective - Participant Rating of Transferred Freehand Gestures

In this section we discus the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a user/participant perspective examining participant ratings of the fit between the freehand gesture and the task for each freehand gesture performed in response to a new user task (H3 and H4). First we discuss this difference in this rating between the metaphor conditions regardless of whether participants performed the sought for freehand gesture. Next we discuss this difference when participants performed the sought for freehand gesture and when they performed another taught freehand gesture. Finally, we discuss the correlation between the rating of the fit between the freehand gesture and the task and the number of sought for transfer of learning of freehand gestures.

Participant Rating of Performed Freehand Gestures

In this section we discuss the participant rating of the fit between the freehand gesture and the task when they perform any freehand gesture in response to a new user task. In examining this relationship we discuss if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures even if these might not be the freehand gesture sought for by the designer/experimenter.

The results report that there was no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition and the *performance metaphor* condition, rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

However, there was a main effect of Session with all participants rating the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*. This suggests that the more the participants perform freehand gestures for new user tasks the better they perceive the suitability of the freehand gestures, even if the performed freehand gestures are not those sought for by the designer/experimenter.

Furthermore, there were main effects of Task Type and Gesture Category. All participants rated the fit between the freehand gesture and the task higher for *Directed* tasks than *Open Ended* tasks. All participants rated the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B, which were rated higher than Category A, which in turn were rated higher than Category C.

Finally, there was an interaction effect between Task Type and Gesture Category. For *Directed* tasks all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B, which were rated higher than Category A, which were rated higher than Category C. For *Open Ended* tasks participants rate the fit between the freehand gesture and the task, when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category A or Category B lower than for *Directed* tasks, however, for Category C this rating was similar to that for *Directed* tasks.

Participant Rating when the Sought For Freehand Gesture is Performed

In this section we discuss the results examining the effect of metaphor, introduced during participant training, on the ratings of the fit between the freehand gesture and the task when participants perform the freehand gesture sought for by the designer/experimenter.

The results report no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition and the *performance metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition. This suggests that the introduction of a metaphor, either a task metaphor or a performance metaphor, better supports participants perception of the suitability of freehand gestures transferred to new user tasks as sought for by the designer/experimenter.

There was a main effect of Session with all participants rating the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*. Comparing the mean rating of the freehand gestures when (i) any freehand gesture is performed and (ii) when the sought for freehand gesture is performed, indicates that when a sought for freehand gesture is performed this rating is higher in both *Session 3* and *Session 4* compared to when the participant performs any freehand gesture. This suggests that the more participants perform freehand gestures for new user tasks the better they perceive the suitability of the freehand gestures for the new user tasks. This is as would be expected prior to the study as the literature suggests that practice on multiple examples supports transfer of learning (e.g. Salomon and Perkins [1989]). Importantly, the perception of suitability over these two sessions is higher for those freehand gestures performed which are sought for by the designer/experimenter.

There was also a main effect of Task Type with all participants rating the fit between the freehand gesture and the task higher for *Directed* tasks than *Open Ended* tasks. Comparing the mean rating of the freehand gestures when (i) any freehand gesture is performed and (ii) when the sought for freehand gesture is performed, indicates that when a sought for freehand gesture is performed this rating is higher for both *Directed* and *Open Ended* tasks. This is as would be expected prior to the study as the literature suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). Importantly, the rating of the suitability of the freehand gesture performed for both *Directed* and *Open Ended* tasks is higher when this freehand gesture is that sought for by the designer/experimenter.

Finally, there was an interaction effect between Task Type and Gesture Category. For *Directed* tasks all participants rate the fit between the freehand gesture and the task when performing the sought for freehand gestures similarly between Category A and Category B but higher than Category C. For *Open Ended* tasks participants rate the fit between the freehand gesture and the task when performing the sought for freehand gesture similarly across all Gesture Categories.

This later result, also suggested from the results examining the number of sought for freehand gestures transferred by participants, might suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category A and Category B. This more mindful learning is reflected in the similar ratings of suitability across all Gesture Categories for new user tasks which we might consider as *far* transfer of learning (i.e. *Open Ended* tasks). Furthermore, this result might suggest that in particular for *far* transfer of learning i.e. *Open Ended* tasks or freehand gestures from Category C, supporting mindful abstraction does support transfer of learning of freehand gestures.

Participant Rating when a Taught Freehand Gesture is Performed

In this section we discuss the participant rating of the fit between the freehand gesture and the task when they perform a taught freehand gesture in response to a new user task. In examining this relationship we discuss if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures when the performed freehand gesture is not the freehand gesture sought for by the designer/experimenter.

The results report no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *performance metaphor* condition, who rate this fit higher than participants in the *no metaphor* condition.

However, there was a main effect of Gesture Category. The results indicate that participants rate the suitability of a taught freehand gesture performed for new user tasks where the sought for freehand gesture was from Category B higher than Category A and Category C.

There was also an interaction effect between Session and Gesture Category. The results indicate that participants rate the suitability of a taught freehand gesture performed for new user tasks where the sought for freehand gesture was from Category A and Category C higher in *Session 4* than in *Session 3*. However, for Category B this rating was higher in *Session 3* than *Session 4*.

Comparing this latter result with the number of sought for freehand gestures transferred from Category B, we can see that both decrease from *Session 3* to *Session 4*. This suggests that the transfer of learning of freehand gestures from Category B is problematic as they transfer less between sessions. However, the rating of the suitability of taught freehand gestures used to perform these new user tasks also decreases between sessions. This lower rating of perceived suitability might prompt users into seeking additional support and allow designers to provide additional training or support.

Finally, there was an interaction effect between the Task Type and Gesture Category. The results indicate that, participants rate the suitability of a taught freehand gesture performed for new user tasks where the sought for freehand gesture was from Category B and Category C higher for *Open Ended* tasks than *Directed* tasks. Whereas, Category A were rated higher for *Directed* tasks than *Open Ended* tasks.

To further examine these results we compare the results reported for (i) the number of sought for freehand gestures transferred across Gesture Categories, (ii) the rating of the suitability of the freehand gestures performed for new tasks which were sought for by the designer/experimenter and (iii) the rating of the taught freehand gestures when used to perform these new user tasks.

For *Directed* tasks participants (i) transfer more sought for freehand gestures from Category A than Category B, than Category C, (ii) rate the suitability of the freehand gestures performed for new tasks which were sought for by the designer/experimenter higher for Category A than Category B, than Category C and (iii) rate taught freehand gestures used to perform these new user tasks higher for Category A than Category B, than Category C. Importantly, the rating of the suitability of the freehand gesture is higher when participants perform the sought for freehand gesture for the new user task. This suggests that Gesture Categories provide a good indication of the ease of transfer of freehand gestures for *near* transfer of learning i.e. *Directed* tasks, both from a designers/experimenters perspective as well as a user/participant perspective.

For *Open Ended* tasks participants (i) transfer more sought for freehand gestures from Category C than Category A and Category B and (ii) rate the suitability of the freehand gestures performed for new tasks which were sought for by the designer/experimenter similarly for Category A, B and C. However, participants rate taught freehand gestures used to perform a new user task where the sought for freehand gesture was from Category B higher than Category A and Category C. Importantly, although the rating of taught freehand gestures performed for the new user task where the sought for freehand gesture was from Category A and Category C is lower than when the sought for freehand gesture is performed, the rating for Category B is similar when the sought for freehand gesture is performed or another taught freehand gesture is performed. This result suggests that the transfer of learning of freehand gestures from Category B is problematic, in particular for *far* transfer of learning (i.e. *Open Ended* tasks).

Correlation Between Suitability and Sought For Transfer of Learning

The results report a correlation between the fit between the freehand gesture and the task and the number of sought for freehand gestures transferred to new user tasks. This result indicates that, as well as indicating ease of learning, participant perception of the suitability of freehand gestures also indicates the ease of transfer of learning of sought for freehand gestures to new user tasks.

However, it is worth noting that where the sought for freehand gesture is from Category B, transfer of learning is often problematic, as discuss above. In particular for *far* transfer of learning i.e. *Open Ended* tasks, although the rating of the fit between the freehand gesture and the task is higher when the sought for freehand gesture is performed for new user tasks, the rating of suitability if another taught freehand gesture is performed is often similarly well rated. This is in contrast to freehand gesture from Category A and C where the rating for sought for freehand gestures is higher than when another taught freehand gesture is performed for the new user task.

5.3 Study II: Un-Prompted Transfer of Learning

In this study, as in Study I, we examine the transfer of learning of freehand gestures and experimentally test the observation made in the literature that there are advantages to supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction), on the transfer of learning of freehand gestures.

The study presented consists of two phases - *Training Phase* and *Transfer of Learning Phase*. The *Training Phase* consists of 2 sessions. In session 1 participants are trained on the freehand gesture set generated in Chapter 3. Participants are trained on the freehand gestures with reference to an example user task e.g. "to stop a video...". Participants are then sent away and asked to return after 7 days to complete session 2. In session 2, participants are tested, and if required, retrained so as to be able to correctly remember and accurately perform each freehand gesture for the corresponding user task. Participants are again sent away and asked to return after 7 days to complete the *Transfer Phase* of the study.

The *Transfer of Learning Phase* again, consists of 2 sessions. In both sessions 3 and 4, participants are read aloud a new set of user tasks and asked to perform any freehand gesture which they felt would best perform that task. Participants were not constrained to the freehand gestures they had been shown during the *Training of Learning Phase* and were encouraged to be as creative as they wished. For each freehand gesture, two new user tasks are presented; a *Directed* user task which contains the same verb for the freehand gesture as presented in the training user task e.g. "to stop recording" and an *Open Ended* user task which uses a synonym of the verb for the freehand gesture presented in the training user task e.g. "to finish listening to a podcast".

Transfer of learning is assessed to have occurred, from a designers/experimenters perspective, if participants perform the freehand gesture sought for prior to the study by the experimenter. Additionally, participant perception of the suitability of the performed freehand gesture for the new user task is used to assess transfer of learning from a user/participant perspective.

In designing the study, Barnett and Ceci [2002] taxonomy is used to identify and control, as far as possible, the factors which might influence transfer of learning. Barnett and Cecis taxonomy proposes a number of dimensions along which studies can be organised. These dimensions are divided into two overall factors - content (i.e. what is transferred) and context (i.e. when and where content is transferred from and to).

Content is further divided into three dimensions - learned skill, performance change and memory demands. In this study participants are told to use any freehand gesture which they feel would best perform the task and are not constrained to the freehand gestures they had been shown during training (learned skill). We suggest this study examines *far* transfer of learning as the freehand gesture performed by participants could be from the learnt freehand gesture set, other gestures from everyday life or newly generated freehand gestures. Transfer of learning is assessed to have occurred if the participant performs the freehand gesture which the experimenter states prior to the study for each new user task presented (performance change). In introducing *Directed* and *Open Ended* user tasks we alter the memory demands to further examine transfer of learning of freehand gestures. *Directed* user tasks invite an automatic performance of the corresponding freehand gesture as the new user task in broadly similar to the user task presented during training. *Open Ended* user tasks seek to examine transfer of learning for dissimilar user tasks where the participant has to think about which taught freehand gesture best performs this unfamiliar user task.

Context is again further divided into six dimensions - knowledge domain, physical context, temporal context, functional context, social context and modality. In this study all participants are told to use the freehand gestures which they feel would best perform the task and are not constrained to the freehand gestures they had been shown during training (knowledge domain). Participants complete the study, individually, as part of a laboratory experiment (physical, functional and social context). The study is conducted over 4 weeks, 2 of which assess transfer of learning (temporal context). Finally, transfer of learning is assessed by presenting participants with new user tasks and examining if the participant performs the freehand gesture which the designer/experimenter states prior to the study (modality). Additionally, transfer of learning is assessed, from a user/participant perspective, by examining the participants perceptions of the suitability of the freehand gestures they perform (modality).

5.3.1 Method

Design

A three factor mixed experimental design was followed. The independent measure was the metaphor presented to the participants. The repeated measures were the Gesture Category and Task Type presented to participants.

The independent measure independent variable was the explanation of the metaphor during training, with three levels (*task metaphor, performance metaphor* or *no metaphor* given). The repeated measures independent variables were 1. the Gesture Category of the freehand gesture with three levels (A, B and C) and 2. Task Type presented with two levels (Directed and Open Ended).

Our primary dependent variable is the selection of an appropriate freehand gesture, measured as the participant choosing the freehand gesture sought for by the experimenter for the user task.

All participants were asked to rate their familiarity with each freehand gesture on a scale of 1..7 (where 1 is not familiar and 7 very familiar). This is, prior to entering the study had the participant encountered or used this freehand gesture before. All participants were asked to give details of this familiarity.

The final dependent variable was the participants perception of the fit between the freehand gesture and the task. This was measured by rating on a scale of 1..7 (where 1 is not well matched and 7 very well matched) in response to the question, *"how well the well do you think the gesture matched the task"* (i.e. the suitability of the freehand gesture for the given user task).

Hypotheses

This study examines (i) if transfer of learning of freehand gestures does occur and (ii) if by supporting both mechanisms of transfer of learning, participants are better able to transfer learnt freehand gestures to new user tasks.

Does Transfer of Learning of Freehand Gesture Occur?

As highlighted in the literature (e.g. Royer [1979]; Salomon and Perkins [1989]; Tuomi-Grohn and Engestrom [2003]) there are many different factors which potentially influence transfer of learning. To address this challenge we utilise Barnett and Ceci [2002] taxonomy to identify and control, as far as possible, the factors which might influence transfer of learning. In designing the study we chose to alter the memory demands factor in Barnett and Ceci taxonomy and as far as possible keep all other factors constant. To alter the memory demands factor we present participants with *Directed* and *Open Ended* user tasks, asking participants to perform any freehand gesture which they feel best performs the new task.

To examine if transfer of learning occurs we hypothesis that,

H1: More freehand gestures sought for by the experimenter, will be performed by participants for new user tasks than other taught freehand gestures, which will be performed more often than new freehand gestures are generated

Furthermore, the literature suggests that transfer of learning will occur more for situations which are more similar to that in which the original knowledge was taught (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). Therefore, we hypothesis that,

H2: More transfer of learning will be observed for Directed user tasks than Open Ended user tasks

The Effect of Supporting Both Mechanisms of Transfer of Learning

Building on the literature, specifically the observation that supporting both mechanisms of transfer of learning has a positive effect on transfer of learning, we hypothesis that the use of metaphor, introduced during participant training, will support the transfer of learning of freehand gestures,

H3: The use of metaphor in training will improve participants transfer of learning of freehand gestures

Furthermore, two types of metaphor are used (i) a *task metaphor* explains the freehand gesture in terms of an example user task or (ii) a *performance metaphor* which describes the physical shape and movement of the freehand gesture. To better understand which type of metaphor better supports transfer of learning of freehand gestures we hypothesised that,

H4: There will be a difference between the effects of task metaphors and performance metaphors on participants transfer of learning of freehand gestures

Participants

Twenty-one participants took part in the study, aged from 18 to 33 with a mean age of 25. 14 participants were male and 7 were female. All participants were right-handed. All participants were recruited from around the University of Bath. Participants were entered into a prize draw to win an Amazon Kindle Fire HD as remuneration for their time.

Procedure

Participants were run individually and randomly allocated to the metaphor experimental condition - *task metaphor, performance metaphor* or *no metaphor* given. The study had two phases - *Training Phase* and *Transfer of Learning Phase*, consisting of 4 sessions in total: two training sessions and two transfer of learning sessions.

Training Phase - Training : Session 1

Participants were trained on the freehand gesture set from Chapter 3. Depending on the randomly allocated condition, each participant was shown a scripted video of each freehand gesture. In all conditions the video first presents an example user task for the freehand gesture (see Table 5.6). In the *task metaphor* and *performance metaphor* conditions the video then presents the metaphor for the freehand gesture. Finally, in all conditions, the video presents a verbal description of the freehand gesture followed by a demonstration.

After watching the video for each freehand gesture, the participant was asked to perform that freehand gesture correctly 10 consecutive times to the experimenter. If an error was made, it was recorded; the participant was shown the video again and asked to perform the freehand gesture correctly 10 consecutive times. This procedure was repeated until the participant correctly performed the freehand gesture 10 consecutive times.

An error was recorded if the experimenter assessed that the performance of the freehand gesture was not the same as demonstrated in the scripted videos. That is, not having the same (i) shape of the hands and fingers, (ii) orientation of the hands, (iii) direction of movement and (iv) speed of movement.

After correctly repeating a freehand gesture to the experimenter, all participants were asked to rate their familiarity with the freehand gesture prior to starting the study, from where they were familiar with the freehand gesture and how well they thought the freehand gesture matched the task.

Participants were sent away and asked to return after 7 days to complete the *Training Phase - Recall and Retrain* session of the study. During the intervening period no further training on the metaphor, freehand gestures or user tasks was given.

Training Phase - Recall and Retrain : Session 2

In the *Training Phase - Recall and Retrain* session, participants were asked to correctly remember and perform the freehand gestures they had been trained on. Participants were run individually. The experimenter read aloud a user task and the participant was asked to perform the corresponding freehand gesture. The order of the freehand gestures was randomised for each participant (i.e. not in the same order in which they had been trained).

If the participant forgot the freehand gesture or performed the freehand gesture incorrectly, the scripted video describing the metaphor (if one was provided) was played. If the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the scripted video describing the freehand gesture was played. Finally, if the participant still could not remember the freehand gesture or could not perform the freehand gesture correctly, the video demonstration of the freehand gesture being performed was played. At each stage, if the participant performed the freehand gesture correctly the experimenter moved on to the next freehand gesture. All errors were recorded.

Participants who were able to correctly remember and perform each freehand gesture in five or less recall and retrain assessments were invited to return after 7 and 14 days to complete the Transfer of Learning Phase of the study.

Transfer of Learning Phase : Sessions 3 and 4

In the *Transfer of Learning Phase* participants were read aloud a new set of user tasks (see Tables 5.7 and 5.8) and asked to perform any freehand gesture which they felt would best perform that task. Participants were not constrained to the freehand gestures they had been shown during the *Training Phase* and were encouraged to be as creative as they wished. New user tasks were either *Directed* i.e. contained the same verb for the freehand gesture as presented in the training user task (e.g. "to stop a video" and "to stop recording") or *Open Ended* i.e. used a synonym of the verb for the freehand gesture presented in the training user task (e.g. "to stop a video" and "to finish listening to a podcast"). The order in which the new set of user tasks were read aloud was randomised.

Participants received no feedback on the 'correctness' of the freehand gesture. Freehand gestures made by participants were recorded by the experimenter. After the participant had performed a freehand gesture they were asked to rate how well they thought the freehand gesture matched the task.

5.3.2 Results

We present the results of this study broken down into three parts. In the first part we present the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

In the second part we present the results examining the effect of supporting both mechanisms of transfer of learning (i.e., learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a designers/experimenters perspective, reporting the results examining the effect of metaphor, introduced during participant training, on the transfer of learning of freehand gesture (H3). We also examine which type of metaphor better supports transfer of learning of freehand gestures (H4).

Additionally, we examine the number of taught freehand gestures transferred by participants. Successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a new user task. Complementary to this, we also examine the generation of new freehand gestures by participants to perform new user tasks i.e. we examine where transfer of learning fails to occur.

In the third part we examine transfer of learning of freehand gestures from a user/participant perspective. We present the results examining participant ratings of the suitability of freehand gestures both when freehand gestures are transferred as sought for by the designer/experimenter as well as when taught freehand gestures are transferred or new freehand gestures generated (H3 and H4).

Does Transfer of Learning of Freehand Gesture Occur?

In this section we report the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2). To examine if transfer of learning occurs we hypothesis that, *more freehand gestures sought for by the experimenter, will be performed by participants for new user tasks than other taught freehand gestures, which will be performed more often than new freehand gestures are generated*.

The results show that all participants performed a sought for freehand gesture for 62% of new user tasks (both *Directed* or *Open Ended*). Overall, this suggests that we can confirm our hypothesis (H1). Furthermore, the results show that all participants perform any taught freehand gesture, i.e. any taught freehand gesture including sought for freehand gestures, for 74% of new user tasks.

Furthermore, the results show that participants in the *task metaphor* condition performed a sought for freehand gesture for 56% of new user tasks (both *Directed* or *Open Ended*). Participants in the *performance metaphor* condition performed a sought for freehand gesture for 63% of new user tasks. Finally, participants in the *no metaphor* condition performed a sought for freehand gesture for 56% of new user tasks.

Examining the number of taught freehand gestures transferred by participants shows that participants in the *task metaphor* condition performed any taught for freehand gesture for 71% of new user tasks. Participants in the *performance metaphor* condition performed any taught for freehand gesture for 78% of new user tasks. Finally, participants in the *no metaphor* condition performed any taught for freehand gesture for 71% of new user tasks.

Additionally, we hypothesis that, *more transfer of learning will be observed for Directed tasks than Open Ended tasks* (H2). All participants performed a sought for freehand gesture for 68% of new *Directed* tasks and for 49% of new *Open Ended* tasks. A one-way ANOVA indicates that this difference is significant (F=5.771, p=0.021) and suggests that we can confirm our hypothesis (H2).

Furthermore, the results show that participants in the *task metaphor* condition performed a sought for freehand gesture for 63% of new *Directed* tasks and for 48% of new *Open Ended* tasks. Participants in the *performance metaphor* condition performed a sought for freehand gesture for 74% of new *Directed* tasks and for 64% of new *Open Ended* tasks. Finally, participants in the *no metaphor* condition performed a sought for freehand gesture for 65% of new *Directed* tasks and for 46% of new *Open Ended* tasks.

Designers/Experimenters Perspective - Sought For Transfer of Learning of Freehand Gestures

This section reports the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a designers/experimenters perspective. This is, for each new user task presented to participants in both sessions of the *Transfer of Learning Phase*, the designer/experimenter stated which freehand gesture should be used. Successful transfer of learning, from a designer/experimenter perspective, is the transfer of a specific freehand gesture for a given user task (H3). The results reported also examine which type of metaphor better supports transfer of learning of freehand gestures (H4).

Additionally, we examine the number of taught freehand gestures transferred by participants. Successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a new user task. Complementary to this, we examine the generation of new freehand gestures by participants to perform new user tasks i.e. examining where transfer of learning fails to occur.

Sought For Transfer of Learning

This section examines the effect of metaphor, introduced during participant training, on the number of freehand gestures transferred by participants which were sought for by the designer/experimenter.

A four-way mixed ANOVA was conducted, with three repeated measures (Session, Task Type and Gesture Category) and one independent measure (metaphor condition). Session refers to the two sessions of the *Transfer of Learning Phase*. Task Type refers to either a *Directed* or *Open Ended* task.

The results report that there was no main effect of metaphor condition (F=0.165, p=0.850). Although not statistically significant, examining the means indicates that participants in the *performance metaphor* condition (*m*=11.37, *sd*=1.89) transfer more sought for freehand gestures than participants in the *task metaphor* condition (*m*=10.08, *sd*=1.89), who transfer more sought for freehand gestures than participants in the *no metaphor* condition (*m*=9.94, *sd*=2.11).

However, there was a main effect of Task Type (F=15.034, p=0.003). Examining the means shows that more sought for transfer of learning of freehand gestures occured for *Directed* tasks (*m*=12.01, *sd*=1.22) than *Open Ended* tasks (*m*=8.92, *sd*=1.19).

There was also a main effect of Gesture Category (F=8.060, p=0.002) with contrasts revealing that for all participants, sought for transfer of learning of freehand gestures occured less for freehand gestures from Category C compared to freehand gestures from Category A (F=14.483, p=0.003) and Category B (F=14.373, p=0.003). There was no such difference between Category A and Category B (F=0.048, p=0.831).

There was an interaction effect between Task Type and Gesture Category (F=23.454, p<0.001). Contrasts reveal that, between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the sought for transfer of learning of freehand gestures between Category A and Category B (F=6.837, p=0.024), Category A and Category C (F=32.801, p<0.001) as well as Category B and Category C (F=31.555, p<0.001).

Examination of the means indicates that for *Directed* tasks, all participants transfer more sought for freehand gestures from Category B (*m*=15.02, *sd*=1.89) than Category A (*m*=13.35, *sd*=1.16), than Category C (*m*=7.65, *sd*=1.04). For *Open Ended* tasks, all participants transfer more sought for freehand gestures from Category A (*m*=9.72, *sd*=1.15) than Category B (*m*=8.58, *sd*=1.54), than Category C (*m*=8.47, *sd*=1.30).

Transfer of Learning of Taught Freehand Gestures

This section examines the effect of metaphor, introduced during participant training, on number of taught freehand gestures transferred by participants. Successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a given task.

A four-way mixed ANOVA reports no main effect of metaphor condition (F=0.164, p=0.851). Although not statistically significant, examining the means indicates that participants in the *performance metaphor* condition (*m*=14.15, *sd*=1.90) transfer more taught freehand gestures than participants in the *task metaphor* condition (*m*=12.83, *sd*=1.90) and *no metaphor* condition (*m*=12.75, *sd*=2.13).

However, there was an interaction effect between Gesture Category and metaphor condition (F=3.796, p=0.016). Contrasts reveal that, between the metaphor conditions, there is a statistically significant difference in the transfer of learning of taught freehand gestures between user tasks where the sought for freehand gesture was from Category A and Category B (F=9.595, p=0.004).

Examination of the means indicates that participants in the *performance metaphor* and *no metaphor* conditions transfer more taught freehand gestures to user tasks where the sought for freehand gesture was from Category A (*m*=16.85, *sd*=1.79 and *m*=13.25, *sd*=2.0 respectively) than Category B (*m*=12.70, *sd*=2.10 and *m*=12.81, *sd*=2.35 respectively). Whereas, participants in the *task metaphor* condition transfer more taught freehand gestures to user tasks where the sought for freehand gesture was from Category B (*m*=15.35, *sd*=2.10) than Category A (*m*=12.80, *sd*=1.79).

There was a main effect of Task Type (F=12.034, p=0.005). Contrasts reveal that more transfer of learning of taught freehand gestures occurs for *Directed* tasks (m=14.44, sd=1.22) than *Open Ended* tasks (m=12.05, sd=1.17).

There was a main effect of Gesture Category (F=5.016, p=0.016). Contrasts reveal that for all participant, transfer of learning of taught freehand gestures occurs more where the sought for freehand gesture was from Category A compared to Category C (F=8.114, p=0.016). There was no such difference between Category A and Category B (F=1.088, p=0.319) and between Category B and Category C (F=3.497, p=0.067).

There was an interaction effect between Task Type and Gesture Category (F=13.215, p=0.001). Contrasts reveal that, between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the transfer of learning of taught freehand gestures between user tasks where the sought for freehand gesture was from Category A and Category B (F=4.994, p=0.048), Category A and Category C (F=16.493, p=0.002) as well as Category B and Category C (F=16.995, p=0.002).

Examination of the means indicates that for *Directed* tasks, all participants transfer more taught freehand gestures where the sought for freehand gesture was from Category B (m=16.18, sd=1.49) than Category A (m=15.66, sd=1.03), than Category C (m=11.48, sd=1.50). Whereas, for *Open Ended* tasks all participants transfer more taught freehand gestures where the sought for freehand gesture was from Category A (m=12.94, sd=1.23) than Category C (m=12.14, sd=1.25), than Category B (m=11.06, sd=1.38).

There was also an interaction effect between Session, Task Type and Gesture Category (F=5.204, p=0.014). Contrasts reveal that, between *Directed* and *Open Ended* tasks between *Session 3* and *Session 4*, there is a statistically significant difference in the transfer of learning of taught freehand gestures between user tasks where the sought for freehand gesture was from Category A and Category C (F=22.154, p=0.001). Examining the means show that for *Directed* tasks all participants transfer more taught freehand gestures when the sought for freehand gesture was from Category A than Category C. For freehand gestures from Category A, participants transfer more in *Session 4* (m=16.44, sd=1.35) compared to *Session 3* (m=14.83, sd=0.92) whereas, for Category C participants transfer similarly between *Session 3* (m=11.35, sd=1.31) and *Session 4* (m=11.62, sd=1.78).

However, for *Open Ended* tasks, in *Session 3* participants transfer more taught freehand gestures where the sought for freehand gesture was from Category A (m=13.93, sd=1.14) than Category C (m=11.38, sd=1.10). Conversely, in *Session 4* participants transfer more taught freehand gestures from Category C (m=12.90, sd=1.53) than Category A (m=11.95, sd=1.57). Furthermore, for *Open Ended* tasks more taught freehand gestures from Category A are transferred in *Session 3* (m=13.93, sd=1.14) compared to *Session 4* (m=11.95, sd=1.57), however, for Category C more taught freehand gestures are transferred in *Session 4* (m=12.90, sd=1.53) compared to *Session 3* (m=11.38, sd=1.10).

Generation of New Freehand Gestures

This section examines the generation of new freehand gestures by participants to perform new user tasks i.e. where transfer of learning fails to occur.

A four-way mixed ANOVA reports no main effect of metaphor (F=0.150, p=0.862). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=8.25, *sd*=1.93) and *no metaphor* condition (*m*=8.35, *sd*=2.15) generate more new freehand gestures than participants in the *performance metaphor* condition (*m*=6.98, *sd*=1.93).

However, there was an interaction effect between Gesture Category and metaphor condition (F=3.865, p=0.016). Contrasts reveal that, between the metaphor conditions, there is a statistically significant difference in the generation of new freehand gestures for user tasks where the sought for freehand gesture was from Category B compared to Category A (F=8.126, p=0.005).

Examination of the means indicates that participants in the *performance metaphor* and *no metaphor* condition generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category B (*m*=8.70, *sd*=2.18 and *m*=8.50, *sd*=2.44 respectively) than Category A (*m*=4.15, *sd*=1.79 and *m*=7.50, *sd*=2.00 respectively). In contrast, participants in the *task metaphor* condition generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category A (*m*=8.20, *sd*=1.79) than Category B (*m*=5.95, *sd*=2.18).

There was a main effect of Task Type (F=12.129, p=0.005) with contrasts revealing that more new freehand gestures were generated for *Open Ended* tasks (*m*=9.08, *sd*=1.18) than *Directed* tasks (*m*=6.65, *sd*=1.24).

There was a main effect of Gesture Category (F=4.658, p=0.021). Contrasts reveal that for all participant, the generation of new freehand gestures occurs more for user tasks where the sought for freehand gesture was from Category C compared to Category A (F=8.126, p=0.005). There was no such difference between Category A and Category B (F=2.521, p=0.162) as well as between Category B and Category C (F=2.725, p=0.127).

Finally, there was an interaction effect between Session, Task Type and Gesture Category (F=4.287, p=0.027). Contrasts reveal that, between *Directed* and *Open Ended* tasks between *Session 3* and *Session 4*, there is a statistically significant difference between the generation of new freehand gestures for user tasks where the sought for freehand gesture was from Category A and Category C (F=20.421, p=0.001). Examining the means show that for *Directed* tasks all participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category C than Category A. Where the new user task sought for a freehand gesture was from Category A, participants generate more new freehand gestures in *Session 3* (*m*=6.17, *sd*=0.92) than *Session 4* (*m*=4.52, *sd*=1.35). Whereas, when the new user task sought for a freehand gesture was from Category C, participants generate new freehand gestures similarly between *Session 3* (*m*=9.65, *sd*=1.75) and *Session 4* (*m*=9.38, *sd*=1.75).

In contrast, for *Open Ended* tasks, in *Session 3* participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category C (*m*=9.67, *sd*=1.10) than Category A (*m*=7.07, *sd*=1.14). However, in *Session 4* participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category A (*m*=9.05, *sd*=1.57) than Category C (*m*=8.03, *sd*=1.50). Furthermore, for *Open Ended* tasks, more new freehand gestures are generated for user tasks where the sought for freehand gesture was from Category A in *Session 4* (*m*=9.05, *sd*=1.57) than *Session 3* (*m*=7.07, *sd*=1.14). Whereas, for user tasks where the sought for freehand gesture was from Category C more new freehand gestures are generated in *Session 3* (*m*=9.67, *sd*=1.10) than *Session 4* (*m*=8.03, *sd*=1.50).

User/Participant Perspective - Participant Rating of Transferred Freehand Gestures

This section reports the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We examine transfer of learning of freehand gestures from a user/participant perspective. That is we examine the participant rating of the fit between the freehand gesture and the task for each freehand gesture performed in response to a new user task (H3 and H4). First we examine if there is a difference in this rating between the metaphor conditions regardless of whether participants performed the sought for freehand gesture. Next we examine this difference when participants performed the sought for freehand gesture, when they performed another taught freehand gesture and when they generate a new freehand gesture. Finally, we examine if there is a correlation between the rating of the fit between the freehand gesture and the task and the number of sought for transfer of learning of freehand gestures.

Participant Rating of Performed Freehand Gestures

This section examines participant rating of the fit between the freehand gesture and the task when they perform any freehand gesture in response to a new user task. In examining this relationship we examine if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures even if these might not be the freehand gesture sought for by the designer/experimenter.

A four-way mixed ANOVA was conducted, with three repeated measures (Session, Task Type and Gesture Category) and one independent measure (metaphor condition). Session refers to the two sessions of the *Transfer of Learning Phase*. Task Type refers to either a *Directed* or *Open Ended* task.

The results report no main effect of metaphor condition (F=0.689, p=0.522). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=5.93, *sd*=0.34) and *performance metaphor* condition (*m*=5.76, *sd*=0.36) rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition (*m*=5.35, *sd*=0.38).

There was a main effect of Task Type (F=7.868, p=0.017). Contrasts reveal that all participants rate the fit between the freehand gesture and the task higher for *Directed* tasks (*m*=5.73, *sd*=0.21) compared to *Open Ended* tasks (*m*=5.62, *sd*=0.20).

There was also a main effect Gesture Category (F=11.832, p=0.001). Contrast revel than for all participants the is a statistically significant different in the rating the fit between the freehand gesture and the task between Category A and Category B (F=13.323, p=0.004) as well as between Category B and C (F=17.857, p=0.001). There was no such difference between Category A and Category C (F=2.807, p=0.122). Examining the means shows that all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B (*m*=5.88, *sd*=0.21), than Category A (*m*=5.64, *sd*=0.20), than Category C (*m*=5.52, *sd*=0.21).

There was an interaction effect between Session and Task Type (F=4.844, p=0.050) . Contrast revel that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* (*m*=5.81, *sd*=0.20) than in *Session 3* (*m*=5.66, *sd*=0.22). However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task similarly between *Session 4* (*m*=5.64, *sd*=0.19) and *Session 3* (*m*=5.61, *sd*=0.22).

Finally, there was an interaction effect between Task Type and Gesture Category (F=8.884, p=0.003). Contrasts reveal that between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the rating of fit between the freehand gesture and the task, between freehand gestures in Category A and Category C (F=28.043, p$<$0.001). There was no such difference between Category B and Category C (F=4.446, p=0.059) as well as between Category A and Category B (F=2.957, p=0.113).

Examination of the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category A (*m*=5.78, *sd*=0.20) than Category C (*m*=5.47, *sd*=0.21). However, for *Open Ended* tasks all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category C (*m*=5.56, *sd*=0.22) than Category A (*m*=5.50, *sd*=0.21).

Participant Rating when the Sought For Freehand Gesture is Performed

This section examines the effect of metaphor, introduced during participant training, on participant ratings of the fit between the freehand gesture and the task when they perform the freehand gesture sought for by the designer/experimenter.

A four-way mixed ANOVA reported no main effect of metaphor condition (F=0.688, p=0.523). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=6.0, *sd*=0.31) and the *performance metaphor* condition (*m*=6.0, *sd*=0.31) rate the fit between the freehand gesture and the task higher when performing a sought for freehand gesture in response to a new user task than participants in the *no metaphor* condition (*m*=5.53, *sd*=0.34).

There was an interaction effect between Session and Task Type (F=7.606, p=0.019) . Examining the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* (*m*=5.98, *sd*=0.20) than in *Session 3* (*m*=5.82, *sd*=0.22). However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 3* (*m*=5.88, *sd*=0.18) than in *Session 4* (*m*=5.69, *sd*=0.19).

Participant Rating when any Taught Freehand Gesture is Performed

This section examines participant rating of the fit between the freehand gesture and the task when they perform a taught freehand gesture in response to a new user task. We examine if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures when successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a given task.

A four-way mixed ANOVA reported no main effect of metaphor condition (F=0.741, p=0.499). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=5.95, *sd*=0.35) and *performance metaphor* condition (*m*=5.87, *sd*=0.35) rate the fit between the freehand gesture and the task higher when performing any taught freehand gesture in response to a new user task than participants in the *no metaphor* condition (*m*=5.34, *sd*=0.40).

There was a main effect of Task Type (F=7.976, p=0.017). Examining the means indicates that all participants rate the fit between the freehand gesture and the task higher for *Directed* tasks (*m*=5.74, *sd*=0.22) compared to *Open Ended* tasks (*m*=5.70, *sd*=0.21).

There was an interaction effect between Session and Task Type (F=6.555, p=0.027) . Examining the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* (*m*=5.85, *sd*=0.21) than in *Session 3* (*m*=5.75, *sd*=0.23). However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 3* (*m*=5.73, *sd*=0.21) than in *Session 4* (*m*=5.55, *sd*=0.23).

Finally, there was an interaction effect between Task Type and Gesture Category (F=4.213, p=0.041). Contrasts reveal that between *Directed* and *Open Ended* tasks, there is a statistically significant difference in the rating of fit between the freehand gesture and the task when participants perform any taught freehand gesture in response to a new user task, between Category A and Category C (F=15.052, p=0.003). There was no such different between Category A and Category B (F=2.038, p=0.181) as well as between Category B and Category C (F=1.531, p=0.242).

Examination of the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task, when performing any taught freehand gesture in response to a new user task, higher where the sought for freehand gesture was from Category A (*m*=5.88, *sd*=0.21), than Category C (*m*=5.62, *sd*=0.24). However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category C (*m*=5.73, *sd*=0.25) than Category A (*m*=5.47, *sd*=0.23).

Participant Rating when a New Freehand Gesture is Generated

This section examines participant rating of the fit between the freehand gesture and the task when participants generate a new freehand gesture in response to a new user task. We examine if there is an effect of metaphor, introduced during participant training, on the perception of the suitability of freehand gestures when transfer of learning fails to occur.

A four-way mixed ANOVA reported no main effect of metaphor condition (F=0.952, p=0.416). Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition (*m*=5.75, *sd*=0.34) rate the fit between the freehand gesture and the task higher for newly generated freehand gestures in response to a new user task than participants in the *performance metaphor* condition (*m*=5.26, *sd*=0.34), than participants in the *no metaphor* condition (*m*=5.10, *sd*=0.37).

There was a main effect Gesture Category (F=5.585, p=0.002). Contrast revel than for all participants the is a statistically significant different in the rating the fit between the freehand gesture and the task between Category A and Category B (F=12.427, p=0.005) as well as between Category B and Category C (F=25.771, p<0.001). There was no such difference between Category A and Category C (F=0.466, p=0.509). Examining the means shows that all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category B (*m*=5.68, *sd*=0.19), than Category A (*m*=5.27, *sd*=0.18), than Category C (*m*=5.16, *sd*=0.26).

There was an interaction effect between Session and Gesture Category (F=5.520, p=0.014). Contrasts reveal that, between *Session 3* and *Session 4*, there is a statistically significant difference in the rating of fit between the freehand gesture and the task, between freehand gestures in Category A and Category C (F=7.623, p=0.019) as well as between Category A and Category B (F=7.814, p=0.017). There was no such difference between Category B and Category C (F=0.515, p=0.488).

Examining the means shows that, all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category A in *Session 3* (*m*=5.40, *sd*=0.18) than in *Session 4* (*m*=5.13, *sd*=0.21). However, when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category B and Category C, all participants rate the fit between the freehand gesture and the task higher in *Session 4* (*m*=5.81, *sd*=0.17 and *m*=5.37, *sd*=0.27 respectively) than *Session 3* (*m*=5.55, *sd*=0.23 and *m*=4.96, *sd*=0.28 respectively).

Finally, there was an interaction effect between Session, Task Type and Gesture Category (F=5.406, p=0.018). Contrasts reveal that, between *Session 3* and *Session 4*, between *Directed* and *Open Ended* tasks, there is a statistically significant difference between the rating of the fit between the freehand gesture and the task for a new freehand gesture which was generated for a new user task where the sought for freehand gesture was from Category A and Category B (F=12.440, p=0.005) as well as from Category A and Category C (F=7.245, p=0.021). There was no such difference between Category B and Category C (F=0.77, p=0.786).

Examining the means show that in *Session 3*, for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category A (*m*=5.46, *sd*=0.23) than Category B (*m*=5.38, *sd*=0.24), than Category C (*m*=4.88, *sd*=0.29). For *Open Ended* tasks in *Session 3*, all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category B (*m*=5.73, *sd*=0.24) than Category A (*m*=5.34, *sd*=0.20), than Category C (*m*=5.04, *sd*=0.27).

In *Session 4*, all participants rate the fit between the freehand gesture and the task, when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category A, lower than *Session 3* for both for both *Directed* tasks (*m*=5.0, *sd*=0.21) and *Open Ended* tasks (*m*=5.26, *sd*=0.25). In contrast, when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category B and Category C, all participants rate the fit between the freehand gesture and the task higher in *Session 4* for both *Directed* tasks (*m*=5.78, *sd*=0.19 and *m*=5.47, *sd*=0.25 respectively) and *Open Ended* tasks (*m*=5.86, *sd*=0.24 and *m*=5.26, *sd*=0.30 respectively).

Correlation Between Suitability and Sought For Transfer of Learning

A Pearson product-moment correlation showed that as the rating of the fit between the freehand gesture and the task increases, the number of sought for freehand gestures transferred to new user tasks also increases ($r(84)=0.457$, $p<0.001$). This results suggests that, as well as indicating ease of learning, participant perception of the suitability of freehand gestures also indicates the transfer of learning of sought for freehand gestures for new user tasks.

5.3.3 Discussion

In this section we discuss the results examining if transfer of learning of freehand gestures occurred as well as the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. In the first part we discuss the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

In the second part we discuss the results examining the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a designers/experimenters perspective, reporting the results examining the effect of metaphor, introduced during participant training, on the transfer of learning of freehand gesture (H3). We also discuss which type of metaphor better supports transfer of learning of freehand gestures (H4). Additionally, we discuss successful transfer of learning which is more broadly defined as the use of any taught freehand gesture for a new user task. Complementary to this, discuss where transfer of learning fails to occur.

Finally, in the third part we discuss transfer of learning of freehand gestures from a user/participant perspective. We discuss the results examining participant ratings of the suitability of freehand gestures performed in response to new user tasks (H3 and H4).

Does Transfer of Learning of Freehand Gesture Occur?

In this section we discuss the results examining if transfer of learning of freehand gestures occurred and as would have been predicted prior to the study (H1 and H2).

Firstly, we hypothesised that, *"more freehand gestures sought for by the designer/experimenter, will be performed by participants for new user tasks than other taught freehand gestures, which will be performed more often than new freehand gestures are generated"* (H1). The results report that, participants performed a sought for freehand gesture for 62% of new user tasks. Furthermore, participants perform any taught freehand gesture, including sought for freehand gestures, for 74% of new user tasks.

This suggests that we can only partially confirm our hypothesis H1. H1 is partially confirmed as all participant perform more sought for freehand gestures than taught freehand gestures and newly generated freehand gestures. However, participants generate more new freehand gestures (26%) than perform a taught freehand gesture (12%) for a new user task.

Secondly, the literature suggests that transfer of learning will occur more for situations which are more similar to that in which the original knowledge was taught. Therefore, we hypothesised that *"more transfer of learning will be observed for Directed tasks than Open Ended tasks"* (H2). The results report that all participants performed a sought for freehand gesture for 68% of new *Directed* tasks and for 49% of new *Open Ended* tasks with a one-way ANOVA indicating that this difference was statistically significant. This suggests that we can confirm our hypothesis (H2).

Examining these results further indicates that participants in the *performance metaphor* condition (63%) transfer sought for freehand gestures more than participants in the *task metaphor* condition (56%) and *no metaphor* condition (56%). Similarly, participants in the *performance metaphor* condition (78%) performed any taught freehand gesture for new user tasks more than participants in the *task metaphor* condition (71%), and *no metaphor* condition (71%).

Furthermore, the results show that for *Directed* tasks, participants in the *performance metaphor* condition transfer more sought for freehand gestures (74%) than participants in the *task metaphor* condition (63%) and *no metaphor* condition (65%). For *Open Ended* tasks, again participants in the *performance metaphor* condition transfer more sought for freehand gestures (64%) than participants in the *task metaphor* condition (48%) and *no metaphor* condition (46%).

These results suggest that we can be confident that transfer of learning of freehand gestures in this study does occur. That is, when told they could perform any freehand gesture which they felt would best perform the new user task, the majority of the freehand gestures performed were those sought for by the designer/experimenter. Furthermore, it is worth noting that the majority of freehand gestures performed were those participants had been trained on.

Furthermore, these results suggests that supporting both mechanisms of transfer of learning (i.e., learning to automaticity and mindful abstraction) does support the transfer of learning of freehand gestures. Overall participants presented with a performance metaphor transfer more sought for freehand gestures than participants presented with a task metaphor or when no metaphor is presented. Interestingly, the results indicate that the introduction of a task metaphor is no more effective than when no metaphor is introduced during training. This might suggest that training participants with reference to a user task is as good as introducing a task metaphor during training.

Finally, for both *Directed* and *Open Ended* tasks participants presented with a performance metaphor transfer more sought for freehand gestures than participants presented with a task metaphor or when no metaphor is presented. This is in contrast to Study I, where for *Directed* tasks participants presented with a performance metaphor transfer more sought for freehand gestures and for *Open Ended* tasks participants presented with a task metaphor or when no metaphor is presented transfer more sought for freehand gestures.

These results suggest that when there is no indication that a learnt freehand gesture can be used to perform a new user task, the introduction of a performance metaphor better supports transfer of learning. This is both when a new user task is similar (i.e. a *Directed* task) and dissimilar (i.e. an *Open Ended* task) to that used to train users on a freehand gesture. This might suggest that where there is little or no indication that a learnt freehand gesture can be used to interact across devices and applications, training new users on freehand gestures with the introduction of a performance metaphor during training can better support transfer of learning.

Designers/Experimenters Perspective - Sought For Transfer of Learning of Freehand Gestures

In this section we discuss the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a designers/experimenters perspective. Successful transfer of learning from a designer/experimenter perspective is the transfer of a specific freehand gesture to the new user task (H3). The results reported also examine which type of metaphor better supports transfer of learning of freehand gestures (H4). Additionally, we discuss successful transfer of learning which is more broadly defined as the use of any taught freehand gesture for a new user task. Complementary to this, discuss where transfer of learning fails to occur.

Sought For Transfer of Learning

In this section we discus the results which examine the effect of metaphor, introduced during participant training, on the number of freehand gestures transferred by participants which were sought for by the designer/experimenter. Successful transfer of learning, from a designer/experimenter perspective, is the transfer of a specific freehand gesture for a given user task.

The results indicate that, unlike Study I, there was no main effect of metaphor. This result suggests that we should reject our hypothesis H3 and H4. That is, when told to use any freehand gesture they feel best performs the task, supporting both mechanisms of transfer of learning does not better support participants when transferring freehand gestures to analogous tasks as sought for by the designer/experimenter.

Although not statistically significant examining the means however, does indicate that participants in the *performance metaphor* condition transfer more sought for freehand gestures than participants in the *task metaphor* condition and *no metaphor* condition.

The results do indicate that more sought for transfer of learning occurs for *Directed* tasks compared to *Open Ended* tasks. This result helps to further confirm our hypothesis H2 that, *"more transfer of learning will be observed for Directed user tasks than Open Ended user tasks"*.

There was a main effect of Gesture Category with sought for freehand gestures from Category A and B transferred more than freehand gestures from Category C. Furthermore, there was an interaction effect between Task Type and Gesture Category. For *Directed* tasks, all participants transfer more sought for freehand gestures from Category B than Category A, than Category C. For *Open Ended* tasks, all participants transfer more sought for freehand gestures from Category A than Category B, than Category C.

These results are in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g., Thorndike [1906]; Salomon and Perkins [1989]). In this case, for both *Directed* and *Open Ended* tasks, where the sought for freehand gesture was from Category A or Category B, the new user tasks are more similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture when compared to freehand gestures from Category C.

Transfer of Learning of Taught Freehand Gestures

In this section we discuss the effect of metaphor, introduced during participant training, on number of taught freehand gestures transferred by participants. Successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a given task.

The results indicate that, again unlike Study I, there was no main effect of metaphor. This results suggests that we should reject our hypothesis H3 and H4. That is, when told to use any freehand gesture they feel best performs the task, supporting both mechanisms of transfer of learning does not better support participants when transferring taught freehand gestures to analogous tasks.

Although not statistically significant examining the means however, does indicate that participants in the *performance metaphor* condition transfer more taught freehand gestures than participants in the *task metaphor* condition and *no metaphor* condition.

The results do indicate that more transfer of learning of taught freehand gestures occurs for *Directed* tasks compared to *Open Ended* tasks. This result helps to further confirm our hypothesis H2 that *more transfer of learning will be observed for Directed user tasks than Open Ended user tasks*.

The was a main effect of Gesture Category, with more transfer of learning of taught freehand gestures occurring for freehand gestures from Category A than Category C. Furthermore, there was an interaction effect between Task Type and Gesture Category. For *Directed* tasks, all participants transfer more taught freehand gestures from Category B than from Category A, than Category C. For *Open Ended* tasks all participants transfer more taught freehand gestures from Category A than Category C, than Category B.

This result suggests that for near transfer of learning (i.e. *Directed* tasks), freehand gestures from Category A and B are more readily transferred than freehand gestures from Category C. This is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task. In this case, new *Directed* user tasks, are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A and B are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for far transfer of learning (i.e. *Open Ended* tasks) freehand gestures from Category A and Category C are more readily transferred than freehand gestures from Category B. This might suggest that the new user tasks are still sufficiently similar to the user tasks presented in training to trigger automatically the performance of freehand gestures from Category A. Additionally, these results suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category B. Finally, similar to the results reported from Study I, these results suggests that the transfer of learning of freehand gestures from Category B is problematic and further support for new users is needed.

These observations are also suggested by the reported interaction effect between Session, Task Type and Gesture Category. The results indicate that for *Directed* tasks, all participants transfer more taught freehand gestures from Category A in *Session 4* than *Session 3*. This is in line with the literature which suggests that, practice on multiple examples supports transfer of learning (e.g., Salomon and Perkins [1989]) and that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task.

For *Open Ended* tasks, all participants transfer more taught freehand gestures from Category C in *Session 4* than in *Session 3*. Again, this is in line with the literature which suggests that practice on multiple examples supports transfer of learning and that by supporting the learner in understanding the underlying principle, main idea, strategy or procedure, learnt material is more likely to be transferred to a wider range of new situations (e.g. Salomon and Perkins [1989]).

Generation of New Freehand Gestures

In this section we discuss the effect of metaphor, introduced during participant training, on the generation of new freehand gestures by participants to perform new user tasks. In this section we discuss where transfer of learning fails to occur.

The results indicate that there was no main effect of metaphor on the number of new freehand gestures generated for new user tasks. Although not statistically significant, examining the means indicate that participants in the *no metaphor* condition and the *task metaphor* condition generate more new freehand gestures for new user tasks than participants in the *performance metaphor* condition.

The results do indicate that more new freehand gestures are generated for *Open Ended* tasks compared to *Directed* tasks. This result helps to further confirm our hypothesis H2 that *"more transfer of learning will be observed for Directed user tasks than Open Ended user tasks"*.

There was a main effect of Gesture Category, with more new freehand gestures generated for new user tasks where the sought for freehand gesture was from Category C than Category A. Furthermore, there was an interaction effect between Gesture Category and metaphor condition. Examining the means indicates that participants in the *performance metaphor* condition and *no metaphor* condition generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category B than Category A. In contrast, participants in the *task metaphor* condition generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category A than Category B.

Finally, there was an interaction effect between Session, Task Type and Gesture Category. For *Directed* tasks, all participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category C than Category A. Where for a new user task the sought for a freehand gesture was from Category A, participants generate more new freehand gestures in *Session 3* than *Session 4*. When for a new user task the sought for a freehand gesture was from Category C, participants generate new freehand gestures similarly between *Session 3* and *Session 4*.

In contrast, for *Open Ended* tasks, in *Session 3* participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category C than Category A. However, in *Session 4* participants generate more new freehand gestures for user tasks where the sought for freehand gesture was from Category A than Category C. Furthermore, more new freehand gestures are generated for user tasks where the sought for freehand gesture was from Category A in *Session 4* compared to *Session 3* whereas, for Category C more new freehand gestures are generated in *Session 3* than *Session 4*.

These results suggest that for *near* transfer of learning (i.e. *Directed* tasks), transfer of learning fails to occur when the sought for freehand gesture is from Category C than from Category A. This is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task. In this case, new *Directed* user tasks, are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for *far* transfer of learning (i.e. *Open Ended* tasks), transfer of learning often fails to occur in *Session 3* where the sought for freehand gesture was from Category C whereas, in *Session 4* it is where the sought for freehand gesture was from Category A. This might suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category A. This is in line with the literature which suggests that by supporting the learner in understanding the underlying principle, main idea, strategy or procedure, learnt material is more likely to be transferred to a wider range of new situations.

User/Participant Perspective - Participant Rating of Transferred Freehand Gestures

In this section we discus the results examining the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. We discuss transfer of learning of freehand gestures from a user/participant perspective examining participant ratings of the fit between the freehand gesture and the task for each freehand gesture performed in response to a new user task (H3 and H4). First we discuss this difference in this rating between the metaphor conditions regardless of whether participants performed the sought for freehand gesture. Next we discuss this difference when participants performed the sought for freehand gesture, when they performed another taught freehand gesture and when they generate a new freehand gesture. Finally, we discuss the correlation between the rating of the fit between the freehand gesture and the task and the number of sought for transfer of learning of freehand gestures.

Participant Rating of Performed Freehand Gestures

In this section we discuss the participant rating of the fit between the freehand gesture and the task when they perform any freehand gesture in response to a new user task. In examining this relationship we discuss if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures even if these might not be the freehand gesture sought for by the designer/experimenter.

The results report that there was no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition and the *performance metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

There was a main effect of Task Type with all participants rating the fit between the freehand gesture and the task higher for *Directed* tasks than *Open Ended* tasks. This is, when the new user tasks are similar to those used to train the participants on the freehand gestures, participants perceive the suitability of the performed freehand gesture higher than when the new user tasks are dissimilar to those used to train participants on the freehand gestures.

There was also a main effect of Gesture Category with all participants rating the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category B, than Category A, than Category C.

There was an interaction effect between Session and Task Type. Examining the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*. However, for *Open Ended* tasks, all participants rate this fit similarly between *Session 4* and *Session 3*.

Finally, there was an interaction effect between Task Type and Gesture Category. Examining the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category A than Category C. However, for *Open Ended* tasks all participants rate this fit higher when performing any freehand gesture for a new user task where the sought for freehand gesture was from Category C than Category A.

Participant Rating when the Sought For Freehand Gesture is Performed

In this section we discuss the results examining the effect of metaphor, introduced during participant training, on the ratings of the fit between the freehand gesture and the task when participants perform the freehand gesture sought for by the designer/experimenter.

The results report that there was no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition and the *performance metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition. This suggests that the introduction of a metaphor, either a task metaphor or a performance metaphor, better supports participants perception of the suitability of freehand gestures transferred to new user tasks as sought for by the designer/experimenter.

There was an interaction effect between Session and Task Type. Examining the means indicates that for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*. This result is as would be expected prior to the study as the literature suggests that practice on multiple examples supports transfer of learning and that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task. However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 3* than *Session 4*.

Exploring this results further, examining the number of new freehand gestures generated i.e. where transfer of learning fails, shows that for *Open Ended* tasks participants generate more new freehand gestures in *Session 3* for new user tasks where the sought for freehand gesture was from Category C than Category A. Conversely, participants generate more new freehand gestures in *Session 4* for new user tasks where the sought for freehand gesture was from Category A than Category C.

These observations suggests that for *near* transfer of learning (i.e. *Directed* tasks), freehand gestures from Category A are more readily transferred than freehand gestures from Category C. In this case, new *Directed* tasks are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. However, *Open Ended* tasks are not sufficiently similar to the user tasks presented in training and do not trigger automatically the performance of a freehand gesture. This is reflected in the number of new freehand gestures generated i.e. where transfer fails to occur, and is particularly evident in *Session 4*.

Conversely, these observations suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category A. This might suggest that supporting mindful abstraction supports the transfer of learning of freehand gestures in particular for *far* transfer of learning. However, the results examining the number of new freehand gestures generated i.e. where transfer of learning fails, indicates that it is freehand gestures in Category A where further support for mindful abstraction is needed rather than freehand gestures from Category C.

Participant Rating when any Taught Freehand Gesture is Performed

This section discusses participant rating of the fit between the freehand gesture and the task when they perform a taught freehand gesture in response to a new user task. We examine if there is an effect of metaphor, introduced during participant training, on the perception of suitability of freehand gestures when successful transfer of learning is more broadly defined as the use of any taught freehand gesture for a given task.

The results report that there was no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition and the *performance metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

There was a main effect of Task Type with all participants rating the fit between the freehand gesture and the task higher for *Directed* tasks than *Open Ended* tasks. This results is as would be expected prior to the study as the literature suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task.

There was an interaction effect between Session and Task Type. Examining the means indicates that, for *Directed* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*. However, for *Open Ended* tasks, all participants rate the fit between the freehand gesture and the task higher in *Session 3* than *Session 4*.

Finally, there was an interaction effect between Task Type and Gesture Category. Examining the means indicates that for *Directed* tasks all participants rate the fit between the freehand gesture and the task, when performing any taught freehand gesture in response to a new user task, higher where the sought for freehand gesture was from Category A than Category C. However, for *Open Ended* tasks all participants rate this fit higher where the sought for freehand gesture was from Category C than Category A.

Comparing these results with those examining the number of new freehand gestures generated i.e. where transfer of learning fails, shows that for *Directed* tasks participants generate more new freehand gestures in *Session 3* for new user tasks where the sought for freehand gesture was from Category C than Category A. In *Session 4*, participants generate more new freehand gestures for new user tasks where the sought for freehand gesture was from Category A than Category C.

Similarly, for *Open Ended* tasks participants generate more new freehand gestures in *Session 3* for new user tasks where the sought for freehand gesture was from Category C, than Category A. Conversely, participants generate more new freehand gestures in *Session 4* for new user tasks where the sought for freehand gesture was from Category A than Category C.

These results suggest, also discussed above, that for *near* transfer of learning (i.e. *Directed* tasks), freehand gestures from Category A are more readily transferred than freehand gestures from Category C. In this case, new *Directed* tasks are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture learnt in training i.e. either the sought for freehand gesture or another taught freehand gesture. However, *Open Ended* tasks are not sufficiently similar to the user tasks presented in training and do not trigger automatically the performance of a freehand gesture learnt in training.

Conversely, for *far* transfer of learning (i.e. *Open Ended* tasks), freehand gestures from Category C are more readily transferred than freehand gestures from Category A. These results suggest that freehand gestures in Category C are learnt more mindfully than freehand gestures in Category A. As discussed above, this might suggest that supporting mindful abstraction supports the transfer of learning of freehand gestures, in particular for *far* transfer of learning.

Participant Rating when a New Freehand Gesture is Generated

This section discusses participant rating of the fit between the freehand gesture and the task when participants generate a new freehand gesture in response to a new user task. We examine if there is an effect of metaphor, introduced during participant training, on the perception of the suitability of freehand gestures when transfer of learning fails to occur.

The results report no main effect of metaphor. Although not statistically significant, examining the means indicates that participants in the *task metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *performance metaphor* condition, who rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

Further examination of the means indicates that participants in the *task metaphor* condition, rate the fit between the freehand gesture and the task more similarly when (i) the freehand gesture performed is that sought for by the designer/experimenter and (ii) a new freehand gesture is generated, than participants in the *performance metaphor* condition and *no metaphor* condition. This suggests that the introduction of a task metaphor, might have a negative effect on the transfer of learning of freehand gestures from a user/participant perspective.

There was a main effect Gesture Category. Examining the means shows that all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is generated for a new user task where the sought for freehand gesture was from Category B than Category A, than Category C.

To further explore these results we compare these results with the mean ratings of suitability when participants perform (i) the sought for freehand gesture and (ii) any taught freehand gesture. This comparison indicates that, where the sought for freehand gesture is from Category B participants rate the suitability of a newly generated freehand gesture similarly to when (i) the sought for freehand gesture is performed and (ii) any taught freehand gesture is performed. In contrast, new freehand gesture generated for user tasks where the sought for freehand gesture is from Category A or Category C are rated as less suitable than when (i) the sought for freehand gesture is performed and (ii) a taught freehand gesture is performed. This result suggests, as highlighted from Study I, that the transfer of learning of freehand gestures from Category B is problematic.

There was an interaction effect between Session and Gesture Category. Examining the means shows that, when a new freehand gesture is generated to perform a new user task where the sought for freehand gesture was from Category A, all participants rate the fit between the freehand gesture and the task higher in *Session 3* than *Session 4*. However, when a new freehand gesture is generated to perform a new user task where the sought for freehand gesture was from Category B and Category C, all participants rate the fit between the freehand gesture and the task higher in *Session 4* than *Session 3*.

Finally, there was an interaction effect between Session, Task Type and Gesture Category. Examining the means shows that for *Directed* tasks, in *Session 3* all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is performed for new user tasks where the sought for freehand gesture was from Category A than Category B, than Category C. However, in *Session 4* all participants rate the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category B than

Category C, than Category A.

For *Open Ended* tasks, in *Session 3* all participants rate the fit between the freehand gesture and the task higher when a new freehand gesture is performed for new user tasks where the sought for freehand gesture was from Category B than Category A, than Category C. However, in *Session 4* all participants rate the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category B than from Category C and Category A which were rated similarly.

These results, as highlighted in Study I, suggest that the transfer of learning of freehand gestures from Category B is problematic, in particular for *far* transfer of learning. Comparing these results to the number of (i) sought for freehand gestures transferred to new user tasks and (ii) the number of new freehand gestures generated for new user tasks, indicates that freehand gestures from Category B are transferred more than Category A and C. However, new freehand gesture are also generated more for new user tasks where the sought for freehand gesture is from Category B than Category A and C. In both cases the suitability of the performed freehand gesture is often rated similarly, in particular for *Open Ended* tasks. This suggests that there is a need to further support the transfer of learning of freehand gestures from Category B.

One possible solution is indicated by the interaction effect between Gesture Category and metaphor condition reported from the results examining the number of new freehand gestures generated for new user tasks. These results indicate that participants in the *task metaphor* condition generate fewer new freehand gestures for new user tasks where the sought for freehand gesture is from Category B than participants in the *performance metaphor* condition and *no metaphor*. This suggests that the introduction of a task metaphor might better support the transfer of learning of freehand gesture from Category B.

Correlation Between Suitability and Sought For Transfer of Learning

The results report a correlation between the fit between the freehand gesture and the task and the number of sought for freehand gestures transferred to new user tasks. Overall this result suggests that, as well as indicating ease of learning, participant perception of the suitability of freehand gestures also indicates the ease of transfer of learning of sought for freehand gestures to new user tasks.

However, it is worth noting that overall *far* transfer of learning (i.e. *Open Ended* tasks) is problematic and that further support is needed for new users.

5.4 Discussion: Study I and Study II

Several interesting results emerge from the studies reported above with regard to the transfer of learning of freehand gestures as well as the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures. We discuss the results from Study I and Study II, examining if transfer of learning of freehand gestures occurred (H1 and H2) and the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures (H3 and H4).

5.4.1 Does Transfer of Learning of Freehand Gesture Occur?

The results from Study I and Study II suggest that we can be confident that transfer of learning of freehand gestures in these studies did occur and as predicted prior to the study. Overall, participants in Study I performed a sought for freehand gesture for 70% of new user tasks. Participants in Study II performed a sought for freehand gesture for 62% of new user tasks. Additionally, examining the number of taught freehand gestures transferred by participants i.e. the use of any taught freehand gesture including sought for freehand gestures, showed that participants performed a taught freehand gesture for 74% of new user tasks.

This suggests that for Study I we can confirm our hypothesis H1 that *more freehand gestures sought for by the designer/experimenter, will be performed by participants for new user tasks than other taught freehand gestures*. However, for Study II we can only partially confirm our hypothesis H1. H1 is partially confirmed as all participant performed sought for freehand gestures more than taught freehand gestures or generating new freehand gestures but, participants generated more new freehand gestures (26%) than performed a taught freehand gesture (12%) for a new user task.

Furthermore, the results from Study I report that all participants performed a sought for freehand gesture for 76% of new *Directed* tasks and for 65% of new *Open Ended* tasks. Similarly, the results from Study II report that all participants performed a sought for freehand gesture for 68% of new *Directed* tasks and for 49% of new *Open Ended*. One-way ANOVA tests indicated that these differences were statistically significant.

This suggests that we can confirm our hypothesis H2 that, *more transfer of learning will be observed for Directed tasks than Open Ended tasks*.

Examining the results from Study I further, indicates that participants in the *performance metaphor* condition transfer sought for freehand gestures (74%) more than participants in the *task metaphor* condition (69%) and the *no metaphor* condition (69%). For *Directed* tasks again, participants in the *performance metaphor* condition transfer more sought for freehand gestures (80%) than participants in the *task metaphor* condition (76%) and *no metaphor* condition (78%). For *Open Ended* tasks, participants in the *task metaphor* condition (61%) and *no metaphor* condition (61%) transfer more sought for freehand gestures than participants in the *performance metaphor* condition (56%).

Similarly, examining the results from Study II further, indicated that participants in the *performance metaphor* condition transferred sought for freehand gestures (63%) more than participants in the *task metaphor* condition (56%) and the *no metaphor* condition (56%). For *Directed* tasks again, participants in the *performance metaphor* condition transferred more sought for freehand gestures (74%) than participants in the *task metaphor* condition (63%) and *no metaphor* condition (65%). For *Open Ended* tasks, participants in the *performance metaphor* condition (64%) transferred more sought for freehand gestures than participants in the *task metaphor* condition (48%) and *no metaphor* condition (46%).

Overall, the results from both studies suggest that supporting both mechanisms of transfer of learning does support the transfer of learning of freehand gestures. Furthermore, participants presented with a performance metaphor transferred more sought for freehand gestures than participant presented with a task metaphor or where no metaphor was presented. Interestingly, the results suggest that the introduction of a task metaphor was no more effective than when no metaphor was introduced during training. This might suggest that training participants with reference to a user task is as effective as introducing a task metaphor during pre-use training.

Additionally, the results from Study I indicate that when a new user task is similar to that used to train users on a freehand gesture (i.e. a *Directed* task), a performance metaphor better supports transfer of learning. Conversely, when new user task is dissimilar to that used to train new users on a freehand gesture (i.e. an *Open Ended* task), a task metaphor, or simply training participants on the freehand gesture with reference to the user task, better supports transfer of learning.

In contrast,the results from Study II indicated that for both *Directed* and *Open Ended* tasks participants presented with a performance metaphor transferred more sought for freehand gestures than participants presented with a task metaphor or when no metaphor was presented.

These results suggest that when there is some indication that a learnt freehand gesture can be used to perform a new user task (Study I) the introduction of a performance metaphor during pre-use training can better support new users in transferring freehand gestures across similar devices and applications. Similarly, training new users on freehand gestures with the introduction of a task metaphor, or simply training participants on the freehand gesture with reference to the user task, can better support new users in transferring freehand gestures across dissimilar, or unknown, devices and applications.

However, when there is little or no indication that a learnt freehand gesture can be used to perform a new user task (Study II) the introduction of a performance metaphor better supports transfer of learning. This is both for similar and dissimilar devices and applications.

5.4.2 Study I: Prompted Transfer of Learning

In this section we discuss the results from Study I examining the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures (H3).

We discuss transfer of learning of freehand gestures from both a designers/experimenters perspective and a user/participant perspective. Successful transfer of learning, from a designer/experimenter perspective, is the performance of a specific freehand gesture for a new user task. From a user/participant perspective we examine the rating of the suitability of the freehand gesture performed for the new user task. Additionally, we discuss which type of metaphor better supports transfer of learning of freehand gestures (H4).

The results from Study I suggest that supporting both mechanisms of transfer of learning has a positive effect on the transfer of learning of freehand gestures. From a designer/experimenter perspective, the results indicate that participants in the *performance metaphor* condition transferred more sought for freehand gestures than participants in the *no metaphor condition*. There was no such difference between participants in the *task metaphor* condition and *no metaphor* condition.

From a user/participant perspective, the results report that there was no main effect of metaphor. Although not statistically significant, examining the means indicates that when performing the freehand gesture sought for by the designer/experimenter, participants in the *task metaphor* condition and *performance metaphor* condition rated the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

These results suggest that we can confirm our hypothesis H3 that *the use of metaphor in training will improve participants transfer of learning of freehand gestures*. Moreover, these results suggests that we can confirm our hypothesis H4 that *there will be a difference between the effects of task metaphors and performance metaphors on participants transfer of learning of freehand gestures*. That is, when told to use only freehand gestures they had been trained on, a performance metaphor better supported participants when transferring learnt freehand gestures to analogous tasks as sought for by the designer/experimenter.

Examining the results from Study I further indicates that from a designer/experimenter perspective, more sought for transfer of learning occurred for *Directed* tasks compared to *Open Ended* tasks. Similarly from a user/participant perspective all participants rated the fit between the freehand gesture and the task when performing the freehand gesture sought for by the designer/experimenter higher for *Directed* tasks compared to *Open Ended* tasks.

This result helps to further confirm our hypothesis H2 that *more transfer of learning will be observed for Directed user tasks than Open Ended user tasks*. This results suggests that, as indicated in the literature, transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]).

Furthermore, the results indicate that for *near* transfer of learning (i.e. *Directed* tasks), Gesture Categories provide a good indication as to the ease of transfer of learning of freehand gestures both from a designers/experimenters perspective as well as a user/participant perspective. That is, freehand gestures from Category A were more readily transferred to new tasks than Category B, which were more readily transferred than Category C.

This is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). In this case, new *Directed* tasks, are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A and B are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for *far* transfer of learning (i.e. *Open Ended* tasks), the results suggest that, from a designers/experimenters perspective freehand gestures from Category C are more readily transferred than freehand gestures from Category A and Category B. From a user/participant perspective all participants rate the fit between the freehand gesture and the task, when performing the sought for freehand gestures, similarly for Category A, Category B and Category C. This suggests that freehand gestures from Category C are more mindfully learnt than freehand gestures from Category A and Category B.

Finally, from a designer/experimenter perspective all participants transferred sought for freehand gestures similarly between the two transfer of learning sessions. However, from a user/participant perspective the rating of the fit between the freehand gesture and the task, when performing a freehand gesture sought for by the designer/experimenter, was higher in Session 4 than in Session 3. This suggests that the more participants perform the sought for freehand gestures the more suitable they were perceived for new user tasks. This result is as would be expected prior to the study, as the literature suggests that practice on multiple examples supports transfer of learning (e.g. Salomon and Perkins [1989]).

Failure or Negative Transfer of Learning

Where transfer of learning fails to occur from a designer/experimenter perspective, the results suggest that participants “fall back” on a perceived suitable freehand gesture. Importantly, for freehand gestures from Category A and Category C, this “fall back” freehand gesture was not only perceived as less suitable, compared to when the sought for freehand gesture was performed, but this lower rating of suitability was similar across *Directed* and *Open Ended* tasks. This suggests that the performance of this “fall back” freehand gesture might prompt new users into seeking additional support and allow designers to provide additional training or support.

However, for freehand gestures from Category B, for both *Directed* and *Open Ended* tasks, the rating of the suitability of this "fall back" freehand gesture was similar to when the sought for freehand gesture was performed. This suggests that, whereas when the participants fail to transfer the sought for freehand gesture from Category A and Category C there might be opportunities for new users to identify and designers to provide additional support to new users, these opportunities might not be as easily identified by new users when they fail to transfer the sought for freehand gestures from Category B. Importantly, the results suggested that, unlike freehand gestures in Category A and Category C, the perceived suitability of these "fall back" freehand gestures decreased over time and might prompt new users into seeking additional support.

Finally, it is worth noting that although not statistically significant, examining the mean ratings of the fit between the freehand gesture and the task when a taught freehand gesture rather than the sought for freehand gesture is performed, participants in the *task metaphor* condition rated this fit higher than participants in the *performance metaphor* condition, who rated this fit higher than participants in the *no metaphor* condition. This might suggest that the introduction of a task metaphor during training has a negative effect on transfer of learning from a designer/experimenter perspective.

5.4.3 Study II: Un-Prompted Transfer of Learning

In this section we discuss the results from Study II examining the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the transfer of learning of freehand gestures (H3).

We discuss transfer of learning of freehand gestures from both a designers/experimenters perspective as well as a user/participant perspective. Successful transfer of learning, from a designer/experimenter perspective, is the performance of a specific freehand gesture for a new user task. From a user/participant perspective we examine the rating of the suitability of the freehand gesture performed for the new user task. We also discuss which type of metaphor better supports transfer of learning of freehand gestures (H4).

The results from Study II show that, from both a designer/experimenter and user/participant perspective there was no statistically significant effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures.

This suggests that we should reject our hypothesis H3 that, *"the use of metaphor in training will improve participants transfer of learning of freehand gestures"*. Moreover, these results suggest that we should reject our hypothesis H4 that, *"there will be a difference between the effects of task metaphors and performance metaphors on participants transfer of learning of* *freehand gestures"*.

However, although not statistically significant, examination of the means indicates that from a designer/experimenter perspective, participants in the *performance metaphor* condition transferred more sought for freehand gestures than participants in the *task metaphor* condition and *no metaphor* condition. Similarly, from a user/participant perspective, when performing the freehand gesture sought for by the designer/experimenter, participants in the *task metaphor* condition and *performance metaphor* condition rated the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

This suggests that when told to use any freehand gesture they feel would best perform the given task, a performance metaphor better supported participants when transferring learnt freehand gestures to analogous tasks as sought for by the designer/experimenter (H3 and H4).

Examining the results from Study II further indicates that from a designer/experimenter perspective, more sought for transfer of learning occurred for *Directed* tasks compared to *Open Ended* tasks. This result helps to further confirm our hypothesis H2 that *"more transfer of learning will be observed for Directed user tasks than Open Ended user tasks"*. This result suggests that, as indicated in the literature, transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]).

However, from user/participant perspective, all participants rated the fit between the freehand gesture and the task when performing the freehand gesture sought for by the designer/experimenter, similarly for both *Directed* tasks compared to *Open Ended* tasks. Furthermore, examining the means indicated that for *Directed* tasks, all participants rated the fit between the freehand gesture and the task higher in Session 4 than in Session 3. In contrast, for *Open Ended* tasks, all participants rated the fit between the freehand gesture and the task higher in Session 3 than in Session 4.

The former result is as would be expected prior to the study as the literature suggests that practice on multiple examples supports transfer of learning (e.g. Salomon and Perkins [1989]) and that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]).

Finally, for both *near* and *far* transfer of learning (i.e. *Directed* and *Open Ended* tasks), the results suggest that the introduction of a performance metaphor better supports the transfer of learning of freehand gestures from Category A and Category C. Furthermore, the results also indicate that, for *near* transfer of learning (i.e. *Directed* tasks) further support is needed to better support the transfer of learning of freehand gesture from Category C. Conversely, for *far* transfer of learning (i.e. *Open Ended* tasks) further support is needed to better support the transfer of learning of freehand gesture from Category A.

Failure or Negative Transfer of Learning

Where transfer of learning fails to occur i.e. examining the number of new freehand gestures generated, showed that from a designer/experimenter perspective, more new freehand gestures are generated for new user tasks where the sought for freehand gesture was from Category C than Category A. From a user/participant perspective, all participants rated the fit between the freehand gesture and the task higher when a new freehand gesture was generated for a new user task where the sought for freehand gesture was from Category B than from Category A, than from Category C.

Furthermore, for *Directed* tasks, from a designer/experimenter perspective, all participants generated more new freehand gestures for user tasks where the sought for freehand gesture was from Category C than Category A. Where, for a new user task the sought for a freehand gesture was from Category A, participants generated more new freehand gestures in Session 3 than Session 4. However, where for a new user task where the sought for a freehand gesture was from Category C, participants generated new freehand gestures similarly between Session 3 and Session 4.

In contrast, for *Open Ended* tasks, in Session 3 participants generated more new freehand gestures for new user tasks where the sought for freehand gesture was from Category C than Category A. However, in Session 4 participants generated more new freehand gestures for new user tasks where the sought for freehand gesture was from Category A than Category C.

Interestingly, more new freehand gestures were generated for user tasks where the sought for freehand gesture was from Category A in Session 4 compared to Session 3. Whereas, for new user tasks where the sought for freehand gesture was from Category C more new freehand gestures were generated in Session 3 than Session 4.

These results suggest that from a designer/experimenter perspective, for *near* transfer of learning (i.e. *Directed* tasks), transfer of learning often fails to occur when the sought for freehand gesture is from Category C than from Category A. This is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). In this case, new *Directed* tasks, are sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for *far* transfer of learning (i.e. *Open Ended* tasks), transfer of learning more often failed to occur in Session 3 where the sought for freehand gesture was from Category C whereas, in Session 4 transfer of learning more often failed to occur where the sought for freehand gesture was from Category A. This might suggest that freehand gestures in Category

C were learnt more mindfully than freehand gestures in Category A.

Similarly, from user/participant perspective, for *Directed* tasks in Session 3, participants rated the fit between the freehand gesture and the task higher when a new freehand gesture was performed for new user tasks where the sought for freehand gesture was from Category A than Category B, which were rated higher than Category C. However, in Session 4, all participants rated the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category B than from Category C, which were rated higher than Category A.

For *Open Ended* tasks, in Session 3, all participants rated the fit between the freehand gesture and the task higher when a new freehand gesture was performed for new user tasks where the sought for freehand gesture was from Category B than Category A, which were rated higher than Category C. However, in Session 4, all participants rated the fit between the freehand gesture and the task higher where the sought for freehand gesture was from Category B than from Category C and Category A.

These results, as highlighted in Study I, suggest that the transfer of learning of freehand gestures from Category B is problematic, in particular for *far* transfer of learning. Comparing these results to the number of (i) sought for freehand gestures transferred to new user tasks and (ii) the number of new freehand gestures generated for new user tasks, showed that (i) freehand gestures from Category B were transferred more than Category A and C but (ii) new freehand gestures were also generated more for new user tasks where the sought for freehand gesture is from Category B than Category A and C. In both cases the suitability of the performed freehand gesture was often rated similarly, in particular for *Open Ended* tasks. This suggests that there is a need to further support the transfer of learning of freehand gestures from Category B.

One possible solution is suggested by the results is that for freehand gestures in Category B the introduction of a task metaphor might better support transfer of learning. This is, although participants in the *task metaphor* condition transfer less sought for freehand gestures than participants in the *performance metaphor* condition, participants in the *task metaphor* condition generate fewer new freehand gestures for new user tasks.

5.5 Corroborating the Results from Chapter 3

In this section, as in Chapter 4, we attempt to corroborate the results reported in Chapter 3 Section 3.2. That is, we wish to corroborate the results that (i) as the rating of the fit between the freehand gesture and the task increases, the number of errors in learning decreases, (ii) the Gesture Categories do provide an indication as to the suitability of a freehand gesture and (iii) the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture.

We consider only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. We use the data collected from the two *Training Phase* sessions (i.e. session 1 *Training Phase - Training* and session 2 *Training Phase - Recall and Retrain*) in both Study I and Study II.

Furthermore, we address a limitation identified in Chapter 4 that participants are trained on the freehand gestures by referencing only its interaction task (e.g. *Open, Play* or *Zoom In*). In both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. "to stop a video...").

Hypotheses

As in Chapter 3 we hypothesis that,

H-V1: The better the fit between the freehand gesture and the task (i.e., the more suitable to the freehand gesture), the better the participants will learn a freehand gesture

H-V2: Freehand gestures in Category A will be rated by our participants as a better fit to their respective tasks than freehand gestures in Category B, which in turn will be rated as having better task fit than freehand gestures in Category C

H-V3: Freehand gestures in Category A will have in fewer errors in learning than gestures in freehand gestures in Category B, which in turn will have fewer errors in learning than freehand gestures in Category C

Participants

We consider only the participants in the *no metaphor* condition was used in order to avoid introducing metaphor as a confounding variable. We use the data collected from the two *Training Phase* sessions (i.e. session 1 *Training Phase - Training* and session 2 *Training Phase - Recall and Retrain*) in both Study I and Study II. This was a total of 13 participants, aged from 18 to 32 with a mean age of 24. 11 participants were male and 2 were female. All participants were right-handed.

Results

Suitability and Ease of Learning

The results reported in this section address if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture), the better the participants will learn a freehand gesture (H-V1). We examine the relationship between our participants rating of freehand gestures in response to the question, *"how well the well do you think the gesture matched the task"* and the number of errors in learning made during the *Training Phase - Recall and Retrain* session.

A Pearson product-moment correlation showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased (r(96)=-0.224, p=0.029). This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate ease of learning of freehand gestures and confirms our hypothesis H-V1.

Gesture Categories and the Suitability of a Freehand Gesture

The results reported in this section address if the Gesture Categories proposed in Chapter 3 Section 3.1 do provide an indication as to the suitability of a freehand gesture (H-V2). We examine the ratings of the fit between the freehand gesture and the task for each Gesture Category by our participants in both the (i) *Training Phase - Training* session 1 and (ii) *Training Phase - Recall and Retrain* session 2 .

Tables 5.9 and 5.10 show a summary of the ratings participants gave for each freehand gesture in this study in response to the question, *" how well you thought the gesture matched the task"* after each session.

The mean rating of freehand gestures, taken from *Training Phase - Training* session, in Category A is 5.68 (*sd*=1.39), for Category B is 4.63 (*sd*=1.41) and for Category C is 4.46 (*sd*=1.46). The mean rating of freehand gestures, taken from *Training Phase - Recall and Retrain* session 2, in Category A is 5.40 (*sd*=1.41), for Category B is 5.06 (*sd*=1.35) and for Category C is 4.52 (*sd*=1.42).

To further examine the relationship between the Gesture Categories and the ratings of the fit between the freehand gesture and the task we conducted a one-way ANOVA test. The results from *Training Phase - Training* session, report that there was a statistically significant difference in our participants ratings of the fit between the freehand gesture and the task across the three Gesture Categories (F=18.595, p<0.001). Post hoc Tukey tests indicated that freehand gestures in Category A were rated significantly higher than freehand gestures in Category B (p<0.001) and Category C (p<0.001). There was no such difference between freehand gestures in Category B and Category C (p=0.764).

A one-way ANOVA test from the *Training Phase - Recall and Retrain* session reports that there was a statistically significant difference in our participants ratings of the fit between the freehand gesture and the task across the three Gesture Categories ($F=9.026$, $p<0.001$). Post hoc Tukey tests indicated that freehand gestures in Category A were rated significantly higher than freehand gestures in Category C ($p<0.001$). There was no such difference between freehand gestures in Category A and Category B ($p=0.070$) as well as between Category B and Category C ($p=0.351$).

This results partially supports our hypothesis H-V2. H-V2 is partially supported as participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, rated the suitability of the freehand gestures in Category A higher than freehand gestures in Category C. Although not statistically significant, in both the *Training Phase - Training* session and *Training Phase - Recall and Retrain* session, the mean ratings for each Gesture Category indicate that freehand gestures in Category A are rated higher than Category B, which are rated higher than Category C.

Table 5.9: Rating of the Suitability (i.e. Rating of the Fit Between the Freehand Gesture and the Task) of the Freehand Gestures by Participants in the *No metaphor* Condition Recorded Immediately After the *Training Phase - Training* Session

Freehand Gesture	**Gesture Category**	**Low (1-3)**	**Average (4-5)**	**High (6-7)**	**Mean Rating**
Select	A	1	0	12	6.31
Close	A	0	4	9	5.92
Pick Up	A	1	4	8	5.85
Stop	A	2	2	9	5.69
Drop	A	1	4	8	5.38
Move	A	2	5	6	5.38
Open	A	2	4	7	5.23
Move Forward	B	1	7	5	5.15
Move Back	B	3	4	6	4.92
Zoom In	B	5	5	3	4.31
Zoom Out	B	5	5	3	4.15
Delete	C	1	5	7	5.23
Show Me	C	1	5	7	5.08
Turn Off	C	2	7	4	4.77
Turn On	C	3	7	3	4.31
Play	C	4	8	1	4.08
Go To	C	6	5	2	3.92
Search	C	5	7	1	3.85

Table 5.10: Rating of the Suitability (i.e. Rating of the Fit Between the Freehand Gesture and the Task) of the Freehand Gestures by Participants in the *No metaphor* Condition Recorded Immediately After the *Training Phase - Recall and Retrain* Session

Freehand Gesture	**Gesture Category**	**Low (1-3)**	**Average (4-5)**	**High (6-7)**	**Mean Rating**
Stop	A	1	2	10	6.08
Select	A	1	4	8	5.85
Pick Up	A	1	3	9	5.54
Close	A	2	5	6	5.23
Drop	A	1	8	4	5.08
Move	A	3	5	5	5.00
Open	A	3	5	5	5.00
Move Back	B	2	4	7	5.23
Move Forward	B	0	9	4	5.08
Zoom In	B	3	3	7	5.08
Zoom Out	B	3	4	6	4.85
Delete	C	3	1	9	5.23
Turn Off	C	2	6	5	5.00
Turn On	C	3	5	5	4.69
Show Me	C	4	4	5	4.54
Play	C	3	7	3	4.31
Search	C	3	8	2	4.08
Go To	C	4	9	0	3.77

Gesture Categories and Ease of Learning

The results reported in this section address whether the indication of the suitability of a freehand gesture provided by its Gesture Category also provides an indication as to the ease of learning of the freehand gesture (H-V3). We examine ease of learning for each Gesture Category by our participants at the end of the *Training Phase - Recall and Retrain* session. Where ease of learning was assessed as the number of errors in 1. retention and 2. performance.

Table 5.11 shows the number of errors in retention and performance made for each freehand gesture by all participants. To examine the relationship between the Gesture Categories and the number of errors in retention we conducted a one-way ANOVA test. There was a statistically significant difference in the number of errors in retention across the three Gesture Categories (F=5.766, p=0.004). Post hoc Tukey tests indicated that freehand gestures in Category C produced more errors in retention than freehand gestures in Category A (p=0.028) and Category B (p=0.006). However, there was no such difference between freehand gestures in Category A and Category B (p=0.649).

Examining the relationship between the Gesture Categories and the number of errors in performance, a one-way ANOVA reports a statistically significant difference across the three Gesture Categories (F=3.897, p=0.022). Post hoc Tukey tests indicated that freehand gestures in Category B produced more errors in performance than freehand gestures in Category A (p=0.016). However, there was no such difference between freehand gestures in Category A and Category C (p=0.521) as well as between Category B and Category C (p=0.153).

These results suggest that we can partially confirm our hypothesis H-V3. Examining the mean number of errors in learning shows that, as expected, freehand gestures in Category A produce the lowest number of errors in both retention and performance. Similarly, as expected, participants made more errors in retention for freehand gestures in Category C than freehand gestures in Category B. However, there was no significant difference in the number of errors in performance for freehand gestures in Category B and Category C.

Table 5.11: Errors Made by Participants in the *No Metaphor* Condition in Retention and Performance of Freehand Gestures Recorded at the End of the *Training Phase - Recall and Retrain* Session

Freehand Gesture	**Gesture Category**	**No. Errors: Retention**	**No. Errors: Performance**
Stop	A	1	0
Pick Up	A	2	2
Select	A	4	0
Close	A	4	0
Drop	A	4	1
Open	A	4	4
Move	A	5	4
Zoom Out	B	1	1
Zoom In	B	3	0
Move Back	B	0	6
Move Forward	B	3	6
Turn On	C	3	2
Turn Off	C	4	2
Delete	C	4	3
Search	C	4	3
Play	C	8	0
Show Me	C	7	2
Go To	C	12	1

Discussion

In this section we discuss the results which attempt to corroborate the results reported in Chapter 3. We discuss the results examining (i) the relationship between participants rating of the fit between the freehand gesture and the task and the number of errors in learning (H-V1), (ii) if the Gesture Categories do provide an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated (H-V2) and (iii) if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture (H-V3).

To corroborate the results from Chapter 3 we consider only the participants in the no metaphor condition in order to avoid introducing metaphor as a confounding variable. Furthermore, in both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. “to stop a video...”). This helps to address a limitation identified in Chapter 4 that, by training participants on the freehand gestures by referencing only the interaction task (e.g. *Stop*) we potentially reduce the suitability of the freehand gesture as these freehand gestures were originally selected by maximising their suitability across both interaction tasks and user tasks.

Suitability and Ease of Learning

First we examined if the better the fit between the freehand gesture and the task (i.e. the more suitable to the freehand gesture) the better participants will learn a freehand gesture (H-V1). We examine the rating of freehand gestures, in response to the question *"how well do you think the gesture fitted the task"*, and the number of errors in learning made during the *Training Phase - Recall and Retrain* session by participants in the *no metaphor* condition .

The results of a correlation analysis showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased. This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate ease of learning of freehand gestures and confirms our hypothesis H-V1.

Gesture Categories and the Suitability of a Freehand Gesture

Next we examined if the Gesture Categories proposed in Chapter 3 Section 3.1 do provide an indication as to the suitability of a freehand gesture (H-V2). The results taken from the *Training Phase - Training* session, show that participants rate freehand gestures in Category A significantly higher than freehand gestures in Category B and Category C. However, freehand gestures in Category B and Category C were not rated significantly differently.

The results taken from the *Training Phase - Recall and Retrain* session, show that participants rate freehand gestures in Category A significantly higher than freehand gestures in Category C. However, there was no such difference between freehand gestures in Category A and Category B as well as Category B and Category C.

These results suggest that we should reject our hypothesis H-V2. That is, although across both sessions freehand gestures in Category A are rated significantly higher than freehand gestures in Category C, in the *Training Phase - Training* session, freehand gestures in Category B and Category C were not rated significantly differently. Similarly, in the *Training Phase - Recall and Retrain* session freehand gestures were not rated significantly differently between Category A and Category B as well as Category B and Category C.

However, although not statistically significant, examining the mean ratings for each Gesture Category across both sessions, indicates that freehand gestures in Category A are rated higher than the freehand gestures in Category B, than Category C. These results suggest that Gesture Categories do provide a broad indication of the perceived suitability of the freehand gestures for new users and partially supports our hypothesis H-V2.

Furthermore, unlike in Chapter 3 and Chapter 4 Section 4.4, participants in this study were trained on the freehand gestures with reference to an example user task (e.g. "to stop a video..."). Comparing these two sets of results suggests that the rating of suitability predicted by the Gesture Categories is more linear (i.e. high, average, low) when participants are trained with reference to a user task. Whereas, participants trained with reference to the interaction task broadly rate suitability as either high or low. That is, participants rate highly freehand gestures in Category A and the freehand gestures in Category B where the spatial cognition or spatial frame of the participants who generated the freehand gesture is the same as that of the new user. However, this rating is low for freehand gestures in Category B where the spatial cognition or spatial frame of the participants who generated the freehand gesture is different to that of the new user and freehand gestures in Category C.

Gesture Categories and Ease of Learning

Finally, we examined if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture (H-V3). The results show that, as expected, freehand gestures in Category A produce the lowest number of errors in both retention and performance. Similarly, as expected, participants made significantly more errors in retention for freehand gestures in Category C than freehand gestures in Category B. However, there was no significant difference in the number of errors in performance for freehand gestures in Category B and Category C. These results suggest that we can partially confirm our hypothesis H-V3.

Summary

The results reported above indicate that Gesture Categories do provide an indication as to the perceptions of suitability of the freehand gestures for users other than by whom they were generated. Similarly, the results reported above indicate that Gesture Categories do provide a broad prediction as to the ease of learning of the freehand gestures in that Category. That is, high, medium and low perceptions of suitability and levels of ease of learning for Category A, B and C respectively.

Additionally, as reported in Chapter 3 Section 3.2 and in Chapter 4 Section 4.5, the results reported above suggest that Gesture Categories can provide an indication as to the types of errors most likely to be observed. That is, Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance.

5.6 Corroborating the Results from Chapter 4

In this section we attempt to corroborate the results reported in Chapter 4). That is we wish to corroborate the results that there are advantages to supporting both mechanisms of transfer of learning on the learning of freehand gestures.

We use the data collected from the *Training Phase - Recall and Retrain* session in both Study I and Study II. One limitation of this data is that ease of learning is only assessed in one session, rather than over the course of 4 sessions in Chapter 4. However, we address a limitation identified in Chapter 4 that participants are trained on the freehand gestures by referencing only its interaction task (e.g. *Open, Play* or *Zoom In*). In both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. to stop a video...).

Hypotheses

As in Chapter 4, we hypothesis that the use of metaphor, introduced during user training, will support the user in learning freehand gestures,

H-V4: The use of metaphor in training will improve participants learning of freehand gestures

Similarly, as in Chapter 4, to better understand which type of metaphor supports the learning of freehand gestures we hypothesised that,

H-V5: There will be a difference between the effects of task metaphors and performance metaphors on participants learning of freehand gestures

Participants

We use the data from participants in each metaphor condition collected from the *Training Phase - Recall and Retrain* session in both Study I and Study II. This was a total of 39 participants, aged from 18 to 48 with a mean age of 26. 27 participants were male and 12 were female. All participants were right-handed.

Results

The results reported in this section contribute towards corroborating the results reported in Chapter 4 that supporting both mechanisms of transfer of learning has a positive effect on the learning of freehand gestures. We examine the effect of metaphor, introduced during participant training, on the of learning of freehand gesture (H-V4). We also examine which type of metaphor better supports the learning of freehand gestures (H-V5).

The Effect of Metaphor on the Number of Errors in Learning

The results reported in this section address whether metaphor, introduced during training, supports participants learning of freehand gestures (H-V4). Furthermore, we examine which type of metaphor better supports the learning of freehand gestures (H-V5).

We first examine the effect of metaphor on the errors in learning across all freehand gestures i.e. the effect on this freehand gesture set. Next we examine the effect of metaphor on the errors in learning across the Gesture Categories i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability (high, medium and low respectively) originally observed during the freehand gesture generation study. Where, errors in learning was assessed as the number of errors in 1. retention and 2. accuracy of performance.

The Effect of Metaphor on the Number of Errors in Learning Across All Freehand Gestures

Examining the number of errors in retention a one-way ANOVA test reports that there was not a statistically significant difference in the number of errors in retention between metaphor conditions ($F=0.041$, $p=0.960$). Although not significant, examination of the means shows that participants in the *performance metaphor* condition made fewer errors in retention ($m=10.38$, $sd=5.14$), than participants in the *no metaphor* condition ($m=10.70$, $sd=5.56$), who made fewer errors in retention than participants in the *task metaphor* condition ($m=11.0$, $sd=5.14$).

Similarly, examining the number of errors in performance a one-way ANOVA test reports that there was not a statistically significant difference in the number of errors in performance between metaphor conditions ($F=1.095$, $p=0.347$). Although not significant, examination of the means shows that participants in the *task metaphor* condition made fewer errors in performance ($m=3.09$, $sd=1.45$), than participants in the *performance metaphor* condition ($m=3.85$, $sd=2.38$), who made fewer errors in performance than participants in the *no metaphor* condition ($m=4.60$, $sd=2.99$).

The Effect of Metaphor on the Number of Errors in Learning Across Gestures Categories

We conducted a two-way mixed ANOVA, with one repeated measure (Gesture Category) and one independent measure (metaphor condition). Examining the number of errors in retention reports no main effect of metaphor condition ($F=0.243$, $p=0.786$).

However, there was a main effect of Gesture Category ($F=18.289$, $p<0.001$). Contrasts reveal that all participant made more errors in retention for freehand gestures in Category B compared to freehand gestures in Category A ($F=21.858$, $p<0.001$) and Category C ($F=14.782$, $p=0.001$). Additionally, all participant made more errors in retention for freehand gestures in Category C compared to freehand gestures in Category A ($F=12.002$, $p=0.002$).

Although not significant, examination of the means shows that participants in the *no metaphor* condition made fewer errors in retention for freehand gesture in Category A (*m*=0.30, *sd*=0.22), than participants in the *task metaphor* condition (*m*=0.46, *sd*=0.21) and *performance metaphor* condition (*m*=0.50, *sd*=0.20). Participants in the *performance metaphor* condition made fewer errors in retention for freehand gesture in Category B (*m*=2.50, *sd*=0.76), than participants in the *no metaphor* condition (*m*=2.70, *sd*=0.83) and *task metaphor* condition (*m*=2.82, *sd*=0.79). Finally, participants in the *performance metaphor* condition made fewer errors in retention for freehand gesture in Category C (*m*=0.50, *sd*=0.20), than participants in the *task metaphor* condition (*m*=1.09, *sd*=0.31) who made fewer errors in retention than participants in the *no metaphor* condition (*m*=1.60, *sd*=0.33).

Examining the number of errors in performance the results of a two-way mixed ANOVA indicate that there was no main effect of metaphor condition (F=1.845, p=0.176). Furthermore, there was no main effect of Gesture Category (F=0.121, p=869).

Although not significant, examination of the means shows that participants in the *task metaphor* condition (*m*=1.0, *sd*=0.34) and *performance metaphor* condition (*m*=1.08, *sd*=0.41), made fewer errors in performance for freehand gesture in Category A than participants in the *no metaphor* condition (*m*=1.70, *sd*=0.36). Participants in the *performance metaphor* condition made fewer errors in performance for freehand gesture in Category B (*m*=1.08, *sd*=0.41), than participants in the *task metaphor* condition (*m*=1.36, *sd*=0.43), who made fewer errors in performance than participants in the *no metaphor* condition (*m*=1.70, *sd*=0.45). Finally, participants in the *task metaphor* condition (*m*=1.27, *sd*=0.32) and *performance metaphor* condition (*m*=1.33, *sd*=0.30), made fewer errors in performance for freehand gesture in Category C than participants in the *no metaphor* condition (*m*=1.60, *sd*=0.33).

The Effect of Metaphor on the Suitability of Freehand Gestures

The results reported in this section examine the effect of metaphor, introduced during participant training, on the learning of freehand gestures (H-V4 and H-V5). We first examine the effect of metaphor across all freehand gestures i.e. the effect on this freehand gesture set. Next we examine the effect of metaphor on the Gesture Categories i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability.

The Effect of Metaphor on the Perception of Suitability Across All Freehand Gestures

A one-way ANOVA test reports that there was no statistically significant difference in the rating of the fit between the freehand gesture and the task between metaphor conditions (F=1.342, p=0.276). Although not significant, examination of the means shows that participants in the *task metaphor* condition (*m*=5.55, *sd*=0.75) and *performance metaphor* condition (*m*=5.50, *sd*=0.71), rate the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition (*m*=4.97, *sd*=1.21).

The Effect of Metaphor on the Perception of Suitability Across Gestures Categories

We conducted a two-way mixed ANOVA, with one repeated measure (Gesture Category) and one independent measure (metaphor condition). The results indicate that there was no main effect of metaphor condition (F=1.330, p=0.279).

However, there was a main effect of Gesture Category (F=31.575, p<0.001). Contrasts reveal that all participant rated the fit between the freehand gesture and the task higher for freehand gestures in Category A compared to freehand gestures in Category B (F=10.391, p=0.003) and Category C (F=89.083, p<0.001). Additionally, all participant rated the fit between the freehand gesture and the task higher for freehand gestures in Category B than Category C (F=18.975, p<0.001).

Although not significant, examination of the means shows that participants in the *performance metaphor* condition (*m*=6.13, *sd*=0.24) and *task metaphor* condition (*m*=6.02, *sd*=0.26), rate the fit between the freehand gesture and the task higher for freehand gesture in Category A than participants in the *no metaphor* condition (*m*=5.42, *sd*=0.28). Participants in the *performance metaphor* condition (*m*=5.56, *sd*=0.30) and *task metaphor* condition (*m*=5.55, *sd*=0.33), rate the fit between the freehand gesture and the task higher for freehand gesture in Category B than participants in the *no metaphor* condition (*m*=4.97, *sd*=0.35). Finally, participants in the *task metaphor* condition rate the fit between the freehand gesture and the task higher for freehand gesture in Category C (*m*=5.08, *sd*=0.31), than participants in the *performance metaphor* condition (*m*=4.82, *sd*=0.28), who rate this fit higher than participants in the *no metaphor* condition (*m*=4.54, *sd*=0.32).

Discussion

In this section we discuss the results which attempt to corroborate the results reported in Chapter 4 that supporting both mechanisms of transfer of learning has a positive effect on the learning of freehand gestures. We discuss the effect of metaphor, introduced during participant training, on the of learning of freehand gesture (H-V4). We also discuss which type of metaphor better supports the learning of freehand gestures (H-V5).

To help corroborate the results, we use the data collected from the *Training Phase - Recall and Retrain* session in both Study I and Study II. Furthermore, in both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. to stop a video...). This helps to address a limitation identified in Chapter 4 that, by training participants on the freehand gestures by referencing only the interaction task (e.g. *Stop*) we potentially reduce the suitability of the freehand gesture as these freehand gestures were originally selected by maximising their suitability across both interaction tasks and user tasks.

The Effect of Metaphor on the Number of Errors in Learning

Examining the effect of metaphor on the errors in learning across all freehand gestures (i.e. the effect on this freehand gesture set) as well as across the Gesture Categories (i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability originally observed during the freehand gesture generation study), indicated that there was no effect of metaphor on the number of errors in retention and performance.

This suggests that we should reject our hypothesis H-V4 and H-V5. However, one limitation of the data used is that ease of learning is only assessed in one session, rather than over the course of multiple sessions as in Chapter 4. This might suggest that the results reported in Chapter 4, that supporting both mechanisms of transfer of learning does have a significant effect on ease of learning, should be reconsidered.

Grossman et al. [2009] highlight two types of learning (i) initial learning and (ii) extended learning. Initial learning refers to the immediate learnability of a user interface or interaction technique. Extended learning refers to the transition from novice to expert user. In reconsidering the results from Chapter 4, we might state that supporting both mechanisms of transfer of learning has a significant effect on supporting the extended learning of freehand gestures, that is in supporting the user in the transition between novice to expert user.

Finally, although not statistically significant, examining the means number of errors in retention and performance shows that it is errors in retention which contribute most to the total errors in learning. For errors in retention, examining the means indicates that participants in the *performance metaphor* condition made fewer errors in retention, than participants in the *no metaphor* condition, who made fewer errors in retention than participants in the *task metaphor* condition. It is worth noting that examining the mean numbers of errors in retention reported in Chapter 4 also indicates that participants in the *performance metaphor* condition made fewer errors in retention compared to participants in the *task metaphor* condition and *no metaphor* condition.

The Effect of Metaphor on the Suitability of Freehand Gestures

Next we examined if metaphor, introduced during participant training, has an effect on the participants perception of the fit between the freehand gesture and the task. The results indicate no main effect of metaphor condition on the rating of the fit between the freehand gesture and the task across all freehand gestures (i.e. the effect on this freehand gesture set) as well as across Gesture Categories (i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability originally observed during the freehand gesture generation study).

This suggests that we should reject our hypothesis H-V4 and H-V5. However, although not statistically significant, examining the means shows that participants in the *task metaphor* condition and *performance metaphor* condition rate the fit between the freehand gesture and the task higher than participants in the *no metaphor*. This is consistent with the results examining the total errors in learning presented above, and suggests that supporting both mechanisms of transfer of learning does has a positive effect on the learning of freehand gestures.

There was also a main effect of Gesture Category with all participants rating the fit between the freehand gesture and the task for freehand gesture in Category A higher than Category B which were rated higher than freehand gestures in Category C.

Compared to the results reported from Chapter 4 we can see that, in this study the ratings of suitability for each Gesture Category is more in line with the different levels of suitability identified during the gesture generation study in Chapter 3. In Chapter 4, participants rated freehand gesture in Category A higher than freehand gestures in Category B and Category C. Category B and C were not rated significantly differently. This suggests that by maximising the suitability of selected freehand gestures across both interaction and user tasks, we are primarily maximising the suitability of freehand gestures for interaction with different devices and applications.

This suggests that when training new users on freehand gestures, we should train participants on the freehand gestures by referencing example user tasks as it allows for a better prediction of the suitability of the freehand gestures. This better prediction allows for designers to better understand where new users will encounter difficulty when learning freehand gestures.

Summary

Overall, although the differences in the number of errors in retention and performance, as well as the rating of the fit between the freehand gesture and the task, between metaphor conditions was not statistically significant, examining the means suggests that the introduction of a metaphor during user training did have a positive effect on the learning of freehand gestures. This suggests that we can partially confirm our hypothesis H-V4. Furthermore, the results suggested that we can partially confirm our hypothesis H-V5 as participants in the *performance metaphor* condition made fewer errors in retention which was the primary cause of observed errors in learning.

One possible explanation for the lack of statistical significance, is that the data used to assess ease of learning was collected in only one session, rather than over the course of multiple sessions as in Chapter 4. Comparing the results reported above to the results from Chapter 4, suggests that supporting both mechanisms of transfer of learning does have a significant effect on ease of learning however, this support is most evident for extended learning, or the transition from novice user to expert user.

5.7 Chapter Summary

To support transfer of learning for freehand gestures, the literature suggests that we should support the mechanisms of transfer of learning; 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]).

In this chapter we further investigate how to support mindful abstraction and investigate the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures. Specifically, this chapter investigated,

R02: How can we use metaphor to support mindful abstraction?

R05: Does supporting both mechanisms of transfer of learning make it easier for users to transfer learnt freehand gestures?

The two studies presented in this chapter consisted of two phases - *Training Phase* and *Transfer Phase*. The *Training of Learning Phase* consisted of 2 sessions. In session 1 participants were trained on the freehand gesture set generated in Chapter 3with reference to an example user task e.g. “to open a web browser...” or “to stop a video...”. Participants were then sent away and asked to return after 7 days to complete session 2. In session 2, participants were tested, and if required, retrained so as to be able to correctly remember and accurately perform each freehand gesture for the corresponding user task. Participants were again sent away and asked to return after 7 days to complete the *Transfer of Learning Phase* of the study.

The *Transfer of Learning Phase* again, consisted of 2 sessions. In both sessions 3 and 4, participants were read aloud a new set of user tasks and asked to perform the freehand gesture which they feel would best performed that user task. In Study I, participants were told to only use those freehand gestures which they had been trained on. In Study II, participants were told to use any freehand gesture they felt best performed the task. For each freehand gesture, two new user tasks were presented; a *Directed* task which contained the same verb for the freehand gesture as presented in the training user task and an *Open Ended* task which used a synonym of the verb for the freehand gesture presented in the training user task.

Transfer of learning was assessed to have occurred from a designers/experimenters perspective, if participants performed the freehand gesture sought for prior to the study by the experimenter. Additionally, participant perception of the suitability of the performed freehand gesture for the new user task was used to assess transfer of learning from a user/participant perspective.

The results from Study I and Study II suggested that transfer of learning did occur and that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) did have a positive effect on the transfer of learning of freehand gestures. In Study I, the results indicate that participants presented with a performance metaphor transferred more sought for freehand gestures and rated the suitability of these freehand gestures higher, than participants presented with a task metaphor or where no metaphor was presented.

In Study II, although not statistically significant, the results indicate that participants presented with a task metaphor or performance metaphor transferred more sought for freehand gestures and rated the suitability of these freehand gestures higher, than participants where no metaphor was presented.

Furthermore, in Study I, for *near* transfer of learning (i.e. *Directed* tasks), the Gesture Categories provided a good indication as to the ease of transfer of learning of freehand gestures both from a designer/experimenter perspective as well as a user/participant perspective. This is, freehand gestures from Category A were more readily transferred to new user tasks than Category B, which were more readily transferred than Category C.

This suggested that for *near* transfer of learning the new user tasks were sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A and B are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

In contrast, for *far* transfer of learning (i.e. *Open Ended* tasks), the results suggest that freehand gestures from Category C were more readily transferred than freehand gestures from Category A and Category B. This suggested that freehand gestures from Category C are learnt more mindfully than freehand gestures from Category A and Category B. This is inline with the literate which suggests that by supporting the learner in understanding the underlying principle, main idea, strategy or procedure, learnt material is more likely to be transferred to a wider range of new situations.

Examining where transfer of learning failed to occur from a designer/experimenter perspective, the results from Study I suggested that, participants "fall back" on a perceived suitable freehand gesture. Importantly, for freehand gestures from Category A and Category C, this "fall back" freehand gesture was not only perceived as less suitable compared to when the sought for freehand gesture is performed, but this lower rating of suitability was similar across *Directed* and *Open Ended* tasks. This suggested that the performance of a "fall back" freehand gesture might prompt users into seeking additional support and allow designers to provide additional training or support.

However, for freehand gestures from Category B for both *Directed* and *Open Ended* tasks, the rating of the suitability of this “fall back” freehand gesture was similar to that when the sought for freehand gesture was performed. This suggested that, unlike freehand gesture from Category A and Category C, opportunities for users to identify and designers to provide additional support might not be as easily identified by users when they fail to transfer sought for freehand gestures from Category B. Importantly, the results suggest that, unlike freehand gestures from Category A and Category C, the perceived suitability of these “fall back” freehand gestures decreased over time which might then prompt users into seeking additional support.

The results from Study II suggest that for both *near* and *far* transfer of learning (i.e. *Directed* and *Open Ended* tasks), the introduction of a performance metaphor better supported the transfer of learning of freehand gestures from Category A and Category C. The results also indicated that for *near* transfer of learning further support is needed to support the transfer of learning of freehand gesture from Category C. Conversely, for *far* transfer of learning further support is needed to support the transfer of learning of freehand gesture from Category A.

As reported in Study I, these results suggested that for *near* transfer of learning new user tasks were sufficiently similar to the user tasks presented in training to trigger automatically the performance of a freehand gesture. The observed difference between Gesture Categories is in line with the ease of learning results which suggest that freehand gestures in Category A are more easily learnt (specifically, produce fewer errors in retention) than freehand gestures in Category C and so are more likely to be triggered automatically.

Similarly, for *far* transfer of learning, the results suggest that freehand gestures from Category C were learnt more mindfully than freehand gestures from Category A. This is in line with the literate which suggests that by supporting the learner in understanding the underlying principle, main idea, strategy or procedure, learnt material is more likely to be transferred to a wider range of new situations.

However, in Study II the results suggest that for freehand gestures from Category B the introduction of a task metaphor better supports transfer of learning. Interestingly, this was not because a task metaphor better supported the transfer of learning of sought for freehand gestures, but rather that transfer of learning failed less often than for participants presented with a performance metaphor or where no metaphor was presented. That is, participants in the *task metaphor* condition generated fewer new freehand gestures for new user tasks than participants in the *performance metaphor* condition or *no metaphor* condition.

Finally, in this chapter we attempted to validate the results from Chapter 3 and Chapter 4.

To validate the results from Chapter 3 we examined, (i) the relationship between participant rating of the fit between the freehand gesture and the task and the number of errors in learning, (ii) if the Gesture Categories do provide an indication as to the suitability of a freehand gesture for users other than by whom the freehand gestures were generated and (iii) if the Gesture Categories do provide an indication as to the ease of learning of a freehand gesture.

We considered only the participants in the *no metaphor* condition in order to avoid introducing metaphor as a confounding variable. We used the data collected from the two *Training Phase* sessions from both Study I and Study II. Furthermore, we address a limitation identified in Chapter 4 that participants are trained on the freehand gestures by referencing only its interaction task (e.g. *Open, Play* or *Zoom In*). In both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. to stop a video...).

To address (i) a correlation analysis showed that as the rating of the fit between the freehand gesture and the task increased, the number of errors in learning decreased. This result provides further evidence for the relationship, reported in Chapter 3 Section 3.2, that suitability does indeed indicate ease of learning of freehand gestures.

To address (ii) we examined the ratings of the fit between the freehand gesture and the task by participants in the *no metaphor* condition in the two *Training Phase* sessions. The results suggest participants in our control group, receiving similar training to the participants in Chapter 3 Section 3.2, broadly rated the suitability of freehand gestures as high, average and low corresponding to Gesture Categories A, B and C respectively. This relationship, although not statistically significant, was more clearly delineated when participants were trained with reference to an example user task rather than with reference to an interaction task.

Finally, to address (iii) we examined the number of errors in retention and performance made by participants in the *no metaphor* condition in the *Training Phase - Recall and Retrain* (session 2). The results suggest that participants in our control group made fewer errors in retention and performance for freehand gestures from Category A compared to freehand gestures from Category B and Category C. Furthermore, as expected participants made more errors in retention for freehand gestures in Category C than Category B. However, there was no significant difference in the number of errors in performance for freehand gestures in Category B and Category C.

To validate the results from Chapter 4, we examined the effect of metaphor on the errors in learning and participant ratings of the fit between the freehand gesture and the task. Where, errors in learning was assessed as the number of errors in 1. retention and 2. accuracy of performance. Furthermore, we evaluate errors in learning across all freehand gestures (i.e. the effect on this freehand gesture set) and the Gesture Categories (i.e. generalised categories of freehand gestures which group together freehand gestures based on their different levels of suitability originally observed during the freehand gesture generation study).

We used the data collected from the *Training Phase - Recall and Retrain* session in both

Study I and Study II. One limitation of this data is that ease of learning is only assessed in one session, rather than over the course of 4 sessions in Chapter 4. However, we addressed a limitation identified in Chapter 4 that participants are trained on the freehand gestures by referencing only its interaction task (e.g. *Open, Play* or *Zoom In*). In both Study I and Study II participants are trained on the freehand gestures with reference to an example user task (e.g. to stop a video...).

The results reported no statistically significant difference between metaphor conditions on the number of errors in retention and performance. Although not statistically significant, the results suggest that it was errors in retention which contributed most to participant errors in learning. For errors in retention, the results indicate that participants in the *performance metaphor* condition made fewer errors in retention, than participants in the *no metaphor* condition, who made fewer errors in retention than participants in the *task metaphor* condition. This result is also that reported in Chapter 4.

Similarly, the results reported no statistically significant difference between metaphor conditions on participant perception of the fit between the freehand gesture and the task. Although not statistically significant, examination of the means showed that participants in the *task metaphor* condition and *performance metaphor* condition rated the fit between the freehand gesture and the task higher than participants in the *no metaphor* condition.

These results suggest that the introduction of a metaphor during user training does have a positive effect on the learning of freehand gestures. The results suggest that a performance metaphor provides better support for participant learning of freehand gestures, this is from both a designer/experimenter perspective as well as a user/participant perspective.

One possible explanation for the lack of statistical significance reported, is that the data used to assess ease of learning was collected from only one session rather than over the course of multiple sessions as in Chapter 4. Grossman et al. [2009] highlight two types of learning (i) initial learning and (ii) extended learning. Initial learning refers to the immediate learnability of a user interface or interaction technique i.e. the initial part of the learning curve. Extended learning refers to the transition from novice to expert user i.e. the later part of the learning curve. Comparing the results discussed above to the results from Chapter 4, suggests that supporting both mechanisms of transfer of learning does have an effect on ease of learning however, this effect is most evident for extended learning or the transition from novice user to expert user. As such we might state that, supporting both mechanisms of transfer of learning supports the extended learning of freehand gestures for new users.

The results reported in this chapter indicate that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) does support the transfer of learning of freehand gestures. This is both from a designer/experimenter perspective i.e.

the transfer of a specific, sought for freehand gesture for a new user task, as well as from a user/participant perspective i.e. a higher perception of the suitability of the freehand gesture transferred as sought for by the designer/experimenter.

Overall, the results from Study I suggest that, where there is an indication that previously learnt freehand gestures can be used for interaction with a device or application, the introduction of a performance metaphor during pre-use training better supports the transfer of learning of freehand gestures.

However, the results from Study II suggest that, where there is little or no indication that previously learnt freehand gestures can be used for interaction with a device or application, the introduction of a performance metaphor better supports the transfer of learning of freehand gestures from Category A and Category C, and the introduction of a task metaphor better supports transfer of learning of freehand gestures from Category B.

Chapter 6

Conclusions and Future Work

This chapter draws together the results of Chapters 3, 4 and 5 and presents the main contributions of this thesis. First we present a summary of this thesis detailing the research question and research objectives addressed as well as summarising the outcomes of each chapter. Next we critically examine the results of the studies presented, detailing the contributions made in this thesis and answering our research question *"how can we support the transfer of learning of freehand gestures across different devices and applications'*? Finally, we discuss potential limitations of the work presented and discuss future work.

6.1 Thesis Summary

Freehand gestural interaction, that is gestures performed mid air without holding an input device or wearing markers for tracking, are increasingly being used as an interaction technique for a range of devices and applications. Unlike traditional point-and-click interfaces, gestural interfaces typically provide the user with different freehand gestures for different tasks. For example, whereas opening a music player, selecting a song and moving forward in a playlist is typically accomplished using a series of mouse clicks in a desktop environment, or taps on a touch-screen, gestural interfaces might provide the user with different freehand gestures for *open, play* and *move forward*.

Therefore, one of the challenges for designers, and users, is the need to support the learning of potentially large sets of freehand gestures. However, it is unclear whether a learnt freehand gesture, designed for a particular task on a particular device or application, could be transferred by the user to perform analogous tasks on different and potentially unknown devices and applications.

In this thesis we have addressed this challenge. Specifically, in this thesis we have investigated the transfer of learning of freehand gestures.

In **Chapter 2** we set the scene for this thesis by reviewing the literature on gestural interaction and transfer of learning. Transfer of learning is the "ability to extend what has been learnt in one context [and apply it] to new contexts" [Salomon and Perkins, 1989, p15]. For freehand gestural interaction, transfer of learning is the ability of users to perform previously learnt freehand gestures to interact with different devices and applications. This transfer of learning of freehand gestures is an important challenge and one which has received little attention in the literature. Therefore, the research question addressed in this thesis was,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

Further investigation of the literature (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]) suggested two mechanisms which can support transfer of learning in new learners - 1. learning to new material automaticity and 2. mindful abstraction i.e. gaining an understanding of the underlying principle, technique, strategy, etc. To support learning to automaticity the literature suggested that we should draw on the learners prior knowledge and experience (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). To support mindful abstraction the literature suggested the use of metaphor (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]).

Furthermore, the literature highlighted that there is a distinct advantage to supporting both of these mechanisms of transfer of learning as "teaching people to think about an activity they usually perform mindlessly not only [improves] their performance but they also become able to apply the same learning to entirely new situations" [Salomon and Perkins, 1989, p129].

Therefore, a number of research objectives were proposed to help answer our research question,

R01: How can we draw on the users' prior knowledge and experience to support learning to automaticity?

R02: How can we use metaphor to support mindful abstraction?

R03: How can we support both mechanisms of transfer of learning for new users of freehand gestures?

R04: Does supporting both mechanisms of transfer of learning make freehand gestures easier to learn for new users?

R05: Does supporting both mechanisms of transfer of learning make it easier for users to transfer learnt freehand gestures?

Chapter 3 focuses on supporting the user in learning freehand gestures to automaticity (RO1). To support learning to automaticity the literature suggests that we should draw on the learners prior knowledge and experience. Building on the work by Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010] and others, a generative empirical study was conducted where potential end users propose freehand gestures for given tasks. From this study a freehand gesture set was proposed where each freehand gesture was selected by maximising its suitability across both interaction tasks (e.g. *Open, Stop, Show Me*) and user tasks (e.g. *open a document, stop a video, show me my location*).

Furthermore, three Gesture Categories were proposed which group together selected freehand gestures based on their different levels of suitability. A follow up ease of learning study reported that Gesture Categories broadly predict the suitability and the ease of learning of freehand gestures for new users. The follow up ease of learning study also reported that, the more suitable the freehand gesture is perceived by the new user the easier it is to learn.

Building on these results, **Chapter 4** first examined how to support mindful abstraction (RO2). To support mindful abstraction i.e. understanding the underlying principle, technique, strategy, etc. the literature suggests the use of metaphor. We proposed that a metaphor for the freehand gesture be introduced during pre-use training (RO3). Two types of metaphor were proposed; a *task metaphor* explains the freehand gesture in terms of an example task (e.g. "as though you are widening a view") and a *performance metaphor* which describes the physical shape and movement of the gesture (e.g. "looks like drawing the letter V").

The study presented in this chapter examined the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the learning of freehand gestures for new users (RO4). The results of the study showed that supporting both mechanisms of transfer of learning does significantly support the learning of freehand gestures for new users.

Finally, **Chapter 5** builds on the results from Chapters 3 and 4, first examining how potential end users can generate the metaphors presented during pre-use training (RO2).

Next two related studies were presented which examined the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures (RO5). The first study examined the transfer of learning of freehand gestures when participants are told to use the freehand gestures learnt during training to perform new tasks. The second study examined the transfer of learning of freehand gestures when participants are told they can use any freehand gesture they feel would best perform a new task. The results of these studies showed that supporting both mechanisms of transfer of learning does support the transfer of learning of freehand gestures for new users.

6.2 Discussion of Findings

This section presents the main contributions of this thesis and answers our research question,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

First we discuss, and provide design recommendations for, supporting learning to automaticity of freehand gestures (RO1) and supporting mindful abstraction (RO2). We discuss how to support both of these mechanisms for new users of freehand gestures (RO3). Next, we discuss the effect of supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) on the learning of freehand gestures (RO4). Finally, we discuss the effect of supporting both mechanisms of transfer of learning on the transfer of learning of freehand gestures (RO5), critically examining these results to provide recommendations for designers on how to support the transfer of learning of freehand gestures across different devices and applications (RQ).

6.2.1 Supporting Learning to Automaticity

To support learning to automaticity the literature suggests that we should draw on the learners prior knowledge and experience (e.g. Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). Research in human computer interaction also highlights the importance of drawing on the users prior knowledge and experience to support the ease of learning of new systems (e.g. Shneiderman [1998]; Norman [2002]). As Polson and Kieras [1985] report, where new systems share large numbers of the same task structures and methods of interaction as other systems known to the user, the time to learn is reduced.

Similarly, gestural interaction design also highlights the importance of drawing on the users prior knowledge and experience. Designers often draw on familiar physical or desktop interactions when designing new gestures (e.g. Scheible et al. [2008]; Yoo et al. [2010]; Yatani et al. [2005]). However, a limitation to these designed gestures are that they personal to the designer. That is, although carefully and principally designed, the selected gesture draws on the knowledge and experience of one particular designer.

In contrast, in user generated gesture studies many potential end users propose gestures that they feel best fit a given task (e.g. Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]; Ruiz et al. [2011]). Such studies draw on the prior knowledge and experience of many potential end users with gestures selected based on agreement between all the users that the gesture is the most suitable for a given task, where the more suitable the gesture often being linked to ease of learning (e.g. Wobbrock et al. [2005]).

Contribution 1 : Supporting Learning to Automaticity with User Generated Freehand Gestures

Building on this work, we suggest that freehand gestures generated by potential end users can help support the mechanism of transfer of learning, learning to automaticity, for new users (RO1).

The first contribution of this thesis is to extend the current research on user generated gesture studies to the generation and selection of freehand gestures for interaction across devices and applications. Chapter 3 details one such study. The important requirements of such studies are,

1. Participants are presented with both interaction tasks and user tasks so that freehand gestures are generated by participants for the generalised interaction (e.g. *Open, Stop*) as well as examples of its use on an imagined device or application (e.g. *open a document, stop a video*).

2. Participants are instructed to visualise the devices and applications they might be interacting with. No props or example applications are provided in order to focus the participant on generating freehand gestures that would allow them to perform the task, rather than focusing on the freehand gestures that could be made to interact with a specific device or application.

3. To select a freehand gestures from those generated, designers should maximise three complementary metrics of suitability,

    (a) The number of times a freehand gesture is proposed by the participants

    (b) Agreement (see Wobbrock et al. [2009])

    (c) Guessability (see Wobbrock et al. [2005])

    Where (a) and (b) provide an indication as to the consensus between participants on how suitable the most proposed freehand gesture is for the given task and (c) provides an indication as to how easily guessable a freehand gesture is in the absence of any training.

4. Designers should maximise these metrics of the suitability across both interaction tasks and user tasks. That is, in selecting a freehand gesture designers should maximise consensus between participants that a proposed freehand gesture is suitable to perform the generalised interaction, as well as, an instance of this freehand gestures use on an imagined device or application.

Contribution 2: Predicting the Ease of Learning of Freehand Gestures for New Users

A further contribution resulting from the study in Chapter 3 are three Gesture Categories (A, B and C) which group together selected freehand gestures based on their different levels of suitability (high, average and low respectively).

Category A groups together selected freehand gestures where, from the freehand gesture generation study, the majority of participants propose one freehand gesture with only a few participants proposing alternatives. The freehand gestures proposed by participants for these interaction tasks can be classified as symbolic gestures i.e. gestures which can be understood without speech, are self contained and are often culturally dependent for example, a wave goodbye or a halt gesture, or deictic gestures i.e. pointing gestures. On the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are emblem gestures which have a high level of formalism, they are quotable gestures and often replace speech in human communication.

Category B groups together selected freehand gestures where, participants propose a range of freehand gestures which typically differ in the direction or orientation of the hands however, broadly, the proposed freehand gestures are similar. The freehand gestures proposed by participants for these interaction tasks can be classified as iconic gestures i.e. gestures which picture the content of speech such as drawing the size of a box being described. On the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are mime gestures which perform manipulations on a device or application. Mime gestures are semi-formal in that they are likely to be similar between participants but perhaps differ depending on the spatial cognition or assumed spatial frame of the participant.

Category C groups together selected freehand gestures where, participants propose a wide range of different freehand gestures however, unlike Category B there are no common features across the proposed freehand gestures. The freehand gestures proposed by participants for these interaction tasks can be classified as metaphoric gestures i.e. gestures which portray the ideas of the speaker but not the content directly for example, moving the hand to indicate a gently flowing body of water when taking about a river. On the continuum of gestures proposed by Kendon [2004], these proposed freehand gestures are gesticulation gestures which are largely improvised gestures in human communication and convey ideas rather than conventions (emblems) or manipulations (mimes).

The literature suggests that suitability indicates ease of learning (e.g. Wobbrock et al. [2005]; Nacenta et al. [2013]). This observation was experimentally tested in Chapters 3, 4 and 5 with the results indicating that, the higher new users perceived the suitability of a freehand gesture the fewer errors in learning were made. Furthermore, these results indicated that Gesture Categories broadly predict both the perceived suitability and ease of learning of freehand gestures for new users. This broad prediction of the ease of learning of freehand gestures for new users can be beneficial for designers. For example, designers identifying freehand gestures which are likely to be difficult to learn for new users could conduct further studies to explore alternative freehand gestures.

Furthermore, the results reported regarding errors in retention and performance suggest that Gesture Categories can provide an indication as to the types of errors most likely to be observed. That is, Gesture Category A indicates both ease of retention and performance for new users whereas, Category B indicates ease of retention but difficulty in performance and Category C difficulty in retention but ease of performance. These observations provide designers with additional information to help further focus the type of additional support provided to new users when learning freehand gestures.

Contribution 3: Evaluating the Ease of Learning of Freehand Gestures for New Users

Chapters 3, 4 and 5, experimentally tested the observation made in the literature that suitability indicates ease of learning (e.g. Wobbrock et al. [2005]; Nacenta et al. [2013]). The results reported a correlation between suitability and ease of learning. This was, the higher the new user perceives the suitability of the freehand gesture the fewer errors in learning are made. This relationship provides designers with a way of evaluating and comparing the ease of learning of freehand gestures. For example, designers might compare the ease of learning of their proposed freehand gesture set to those of other designers.

6.2.2 Supporting Mindful Abstraction

To support mindful abstraction i.e. the deliberate abstraction and understanding of a principle, strategy or procedure, the literature suggests the presentation, or use of, metaphor during learning (e.g. Salomon and Perkins [1989]; Haskell [2001]). Metaphor presents an abstraction to the learner of the material so as to convey the key principles, strategies, concepts, etc.

Contribution 4: Using Metaphor to Support Mindful Abstraction

Building on this work, we suggest that the introduction of a metaphor during pre-use training can help support the mechanism of transfer of learning, mindful abstraction, for new users (RO2). In Chapter 4 metaphors were generated by designers. In Chapter 5 potential end users generated and selected suitable metaphors via a series of online questionnaires.

The literature suggests that the choice of metaphor plays an important part in conveying key abstractions to end users (e.g. Gillan and Bias [1994]; Madsen [1994]; Helander et al.

[1997]; Saffer [2005]). As Erickson [1990] highlights, designers should support the areas in that the users understanding is the weakest. We argue that the users understanding is weakest in understanding 1. how the use of a given freehand gesture relates to similar interactions with technology, other people or everyday life or 2. the physical features of the given freehand gesture.

The former is reflected in current approaches to the design of gestural interactions where designers often draw on familiar interaction metaphors to support learning e.g. cocktail mixing (e.g. Yoo et al. [2010]) or cultural gestures such as the *namaste* gesture (Mistry et al. [2009]). The latter builds on the observations from results reported in this thesis that the spatial cognition or spatial frame differences between the generating participants and new users of freehand gestures can cause difficulties when learning freehand gestures, in particular for freehand gestures in Category B (i.e. iconic or mime gestures).

We propose two types of metaphor - task metaphor and performance metaphor. A task metaphor explains the freehand gesture in terms of an example user task e.g. “as though you are widening a view” to zoom in on an image or “as though you are spinning an LP” to play a song. Where spatial information is conveyed by a task metaphor it conveys information about the movements or manipulations on the object. For example, for the Turn On freehand gesture the task metaphor might be “as though you are turning a radio dial” which may be elaborated to include a direction of movement of the dial i.e. “clockwise”.

Conversely, a performance metaphor describes the physical shape and movement of the freehand gesture e.g. “looks like drawing the letter V” to zoom in on an image or “looks like drawing the letter O” to play a song. Where spatial information is conveyed by a performance metaphor it describes movements made by the user for example, “looks like drawing the letter V” might be further elaborated with “moving downwards” or “looks like a rotating you wrist to the right” to turn on a TV.

As part of the study presented in Chapter 4, participants were asked to report how they remembered the freehand gestures they had been trained on. Interestingly, participants presented with a metaphor in pre-use training often did not report the specific metaphor presented during training as how they remembered the freehand gesture. However, these participants did report task like metaphors (e.g. “stopping traffic” or “opening a box”) and performance like metaphors (e.g. “like pushing someone/something”, “showing my palms”). Conversely, participants where no metaphor was presented in pre-use training, by majority reported that they remembered freehand gestures from “life experience” or because it “makes sense” or “by repetition”.

These results suggest that presenting a metaphor during pre-use training does support new users to think mindfully about the freehand gestures they are being trained on.

6.2.3 Supporting Both Mechanisms of Transfer of Learning

In Chapter 2 we discuss current methods of supporting gesture learning and how these methods might be used to support both mechanisms of transfer of learning i.e. learning to automaticity and mindful abstraction (RO3).

Contribution 5: How to Support Both Mechanisms of Transfer of Learning for New Users of Freehand Gestures

For gestural interfaces, current approaches to support the learning of multi-touch gestures include dynamic guides (e.g. Bau and Mackay [2008]) and in situ learning through visual clues or instruction (e.g. Freeman et al. [2009]). However, as Kurtenbach et al. [1994] and Appert and Zhai [2009] highlight, one important limitation to gestural interaction is that "gestures are not self-revealing". This is also a significant challenge for freehand gestural interaction, especially as it is not always clear how learning support mechanisms such as dynamic guides or visual clues could be displayed to the user in particular when interacting across multiple devices and applications.

To support learning to automaticity the literature suggests that we should draw on the learners prior knowledge and experience (e.g.Salomon and Perkins [1989]; Bransford [2000]; Haskell [2001]). Building on the work of Wobbrock et al. [2009]; Fikkert et al. [2010]; Kray et al. [2010]; Ruiz et al. [2011], we suggest that freehand gestures generated by potential end users can support the mechanism of transfer of learning, learning to automaticity, for new users.

To support mindful abstraction, the literature suggests the presentation, or use of, metaphor during learning (e.g. Salomon and Perkins [1989]; Haskell [2001]). To support mindful abstraction during learning we suggest the introduction of metaphor during pre-use training.

6.2.4 Supporting the Learning of Freehand Gestures

The literature (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]) suggests that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) not only supports the transfer of learning of freehand gestures, but also the learning of freehand gestures (RO4). Where, learning to automaticity is supported by training new users on freehand gestures generated by potential end users and mindful abstraction is supported thorough the introduction of metaphor during pre-use training.

Contribution 6: Supporting the Learning of Freehand Gestures for New Users

Chapter 4 experimentally tested this observation and examined the effect of supporting both mechanisms of transfer of learning on the ability of participants to correctly recall and perform freehand gestures (RO4).

The results reported in Chapter 4 show that supporting both mechanisms of transfer of learning has a positive effect on the ease of learning of freehand gestures by new users. Where, ease of learning is assessed as the fewest number of errors in 1. retention and 2. accuracy of performance. Therefore, to support the learning of freehand gestures for new users,

1. Designers should support learning to automaticity through user generated freehand gestures

2. Designers should support mindful abstraction thorough the introduction of metaphor during pre-use training

Furthermore, the results from Chapter 4 suggested that supporting mindful abstraction through the introduction of either a task metaphor or performance metaphor better supports new users of freehand gestures in making fewer errors in retention than where no metaphor is presented. However, the introduction of performance metaphor better supports new users of freehand gestures in making fewer errors in performance than the introduction of a task metaphor, or where no metaphor is presented. Overall the results reported suggest that,

3. Designers should introduce a performance metaphor during pre-use training to support the learning of freehand gestures for new users

Further examination of the these results indicated that participants presented with a task metaphor during pre-use training made fewer errors in learning for freehand gestures in Category A than participants presented with a performance metaphor or where no metaphor was presented. In contrast for freehand gestures in Category B and C, participants presented with a performance metaphor during pre-use training made fewer errors in learning than participants presented with a task metaphor or where no metaphor was presented.

Furthermore, examining how participants presented with a metaphor during pre-use training reported how they remembered the freehand gestures showed that the majority of participants reported a task like metaphor for freehand gestures in Category A and a performance like metaphor for freehand gestures in Category B and C. These results suggest that to further support the ease of learning of freehand gestures for new users,

4. Designers might introduce a task metaphor during pre-use training for freehand gestures in Category A

5. Designers might introduce a performance metaphor during pre-use training for freehand gestures in Category B and C

In Chapter 5 we sought to validate these results. Although not statistically significant, the results indicated that supporting both mechanisms of transfer of learning did have a positive effect on the ease of learning of freehand gestures for new users.

One possible explanation for the lack of statistical significance in Chapter 5, is that the data used to assess ease of learning was collected in only one session, rather than over the course of multiple sessions as in Chapter 4. Grossman et al. [2009] highlight two types of learning (i) initial learning and (ii) extended learning. Initial learning refers to the immediate learnability of a user interface or interaction technique i.e. the initial part of the learning curve. Extended learning refers to the transition from novice to expert user i.e. the later part of the learning curve. Comparing the results reported in Chapter 4 and 5, suggests that supporting both mechanisms of transfer of learning does have a significant effect on ease of learning however, this support is most evident for extended learning i.e. the transition from novice user to expert user.

Furthermore, this better support for ease of learning is from both a designers perspective (i.e. fewer number of errors in learning), and a user perspective (i.e. higher perception of suitability). That is, supporting both mechanisms not only results in fewer errors in learning but also a higher perception of suitability.

These reported results are particularly useful for designers who are interested in supporting the ease of learning of freehand gestures for devices and applications. For example, designers interested in creating a new freehand gesture set for a particular device or application. By drawing on the prior knowledge and experience of potential end users to generate freehand gestures and introducing metaphor during pre-use training, designers can create not only a highly learnable set of freehand gestures but also a set of freehand gestures which are perceived as highly suitable by new users.

6.2.5 Supporting the Transfer of Learning of Freehand Gestures

To support the transfer of learning of freehand gestures, the literature (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]) suggests to support both mechanisms of transfer of learning i.e. learning to automaticity and mindful abstraction (RO5).

Contribution 7: Observations Regarding the Presence and Absence of Transfer of Learning of Freehand Gestures

Our review of the literature on transfer of learning in Chapter 2, highlights that experimental evidence for transfer of learning is often mixed. Studies such as Clements and Gullo [1984]; Lehrer et al. [1988]; Brown [1989]; Salomon et al. [1989a]; Campione et al. [1991] find evidence for transfer of learning whereas as studies such as Gick and Holyoak [1983]; Pea and

Kurland [1984]; Salomon and Perkins [1987]; Mayer and Wittrock [1996] find little evidence for transfer of learning.

In Chapter 5 transfer of learning was assessed to have occurred if participants performed the freehand gesture sought for prior to the study by the designer. The results from the two studies presented in Chapter 5 showed that the transfer of learning of freehand gestures did occur. That is, either when told to use (i) only the freehand gestures they had been trained on to perform new tasks (i.e. Study I - *near* transfer of learning) or (ii) any freehand gesture which they felt would best perform new tasks (i.e. Study II - *far* transfer of learning), the majority of the freehand gestures performed by all participants were those sought for by the designer.

Furthermore, the results from Chapter 5 provide observations regarding the presence and absence of transfer of learning. These results allow designers to predict when transfer of learning of freehand gestures is most likely to occur, and when it is most likely to fail, for new users of freehand gestures interacting across different devices and applications. Overall the results of the two studies presented in Chapter 5 suggest that,

1. New users transfer freehand gestures to new tasks, as sought for by the designer, more when told to use previously learnt freehand gestures. These results suggest that,

    (a) Transfer of learning of freehand gestures occurs more for *near* transfer of learning than *far* transfer of learning. For example, *near* transfer of learning might be where new users are using freehand gestures to interact with a new application on familiar device, whereas *far* transfer of learning might be using freehand gestures to interact with an unfamiliar device.

    (b) Designers of new devices and applications should prompt users that previously learnt freehand gestures can be used for interaction. This is inline with the literature which highlights the positive effect of prompting learners that previously learnt solutions can be used to solve new problems (e.g. Gick and Holyoak [1980]).

2. Transfer of learning of freehand gestures is more likely to occur when performing a similar task to that presented during pre-use training. This result is in line with the literature which suggests that transfer of learning is most likely to be observed when the transfer task is similar to the originally taught task (e.g. Thorndike [1924]; Detterman [1993]; Royer et al. [2005]). For example, the freehand gesture *Move Forward* is more likely to transferred by new users to skip to the next song in a play list having been trained to perform the *Move Forward* freehand gesture to change TV channels. Conversely, the freehand gesture *Move Forward* is less likely to transferred by new users to turn the page in a book having been trained to perform the *Move Forward* freehand gesture to change TV channels.

Further examination of the results of the two studies presented in Chapter 5 suggest recommendations for designers on predicting the transfer of learning of freehand gestures for new users,

3. For *near* transfer of learning of freehand gestures (i.e. where new users know, or are prompted, that they can use previously learnt freehand gestures) when performing new tasks similar to the tasks presented in training, Gesture Categories provide a good indication as to the ease of transfer of learning of freehand gestures.

   This is, freehand gestures from Category A are more readily transferred to new tasks than freehand gestures from Category B, which are more readily transferred than freehand gestures from Category C. Importantly, this is both from a designers perspective (i.e. the transfer of a specific, sought for freehand gesture for a new task) as well as a user perspective (i.e. a higher perception of the suitability of the freehand gesture transferred as sought for by the designer).

4. For *near* transfer of learning of freehand gestures when performing new tasks which are <u>not</u> similar to the tasks presented in training, freehand gestures from Category C are more readily transferred than freehand gestures from Category A and Category B.

5. For *far* transfer of learning of freehand gestures (i.e. where new users are unsure, or are not prompted, that they can use previously learnt freehand gestures) when performing new tasks similar to the tasks presented in training, freehand gestures from Category A are more readily transferred to new tasks than freehand gestures from Category C.

6. For *far* transfer of learning of freehand gestures when performing new tasks which are <u>not</u> similar to the tasks presented in training, freehand gestures from Category C are more readily transferred to new tasks than freehand gestures from Category A.

7. For *far* transfer of learning of freehand gestures, both when performing new tasks similar and not similar to the tasks presented in training, freehand gestures from Category B are problematic and are often not transferred as sought for by the designer.

Contribution 8: Supporting the Transfer of Learning of Freehand Gestures for New Users

The literature (e.g. Salomon and Perkins [1989]; Helander et al. [1997]; Haskell [2001]) suggests that supporting both mechanisms of transfer of learning (i.e. learning to automaticity and mindful abstraction) can support the transfer of learning of freehand gestures (RO5 and RQ).

Chapter 5 experimentally tested the observation. Where, learning to automaticity was supported by training new users on freehand gestures generated by potential end users and mindful abstraction was supported thorough the introduction of metaphor during pre-use training.

Successful transfer of learning, from a designers perspective, was assessed as the ability of participants to perform the freehand gesture sought for prior to the study by the designer. Additionally, the perception of the suitability of the performed freehand gesture for a new task was used to assess transfer of learning from a user perspective.

The results reported showed that supporting both mechanisms of transfer of learning did have a positive effect on the transfer of learning of freehand gestures by new users. This positive effect was both from a designer perspective as well as from a user perspective. Therefore we suggest that to support the transfer of learning of freehand gestures for new users,

1. Designers should support learning to automaticity through user generated freehand gestures

2. Designers should support mindful abstraction thorough the introduction of metaphor during pre-use training

Furthermore, the results from Chapter 5 suggested that supporting mindful abstraction through the introduction of a performance metaphor better supports users in transferring the freehand gesture sought for by the designer to new tasks than the introduction of a task metaphor or where no metaphor is presented. Additionally, the results suggested that user perception of the suitability of the transferred freehand gesture is higher when a performance metaphor is introduced during pre-use training, especially when the transferred freehand gesture is that sought for by the designer. Overall the results reported suggest that,

3. Designers should introduce a performance metaphor during pre-use training to support the transfer of learning of freehand gestures for new users

Additionally, the two studies presented in Chapter 5 investigated the transfer of learning of freehand gestures when participants were told to use (i) only the freehand gestures they had been trained on to perform new tasks (i.e. Study I - *near* transfer of learning) or (ii) any freehand gesture which they felt would best perform new tasks (i.e. Study II - *far* transfer of learning).

These two studies examine *near* and *far* transfer of learning of freehand gestures. For example, *near* transfer of learning might be where new users are using freehand gestures to interact with a new application on familiar device, whereas *far* transfer of learning might be using freehand gestures to interact with an unfamiliar device. Further examination of the results reported in each of the two studies presented in Chapter 5 suggests that,

4. To support *near* transfer of learning, designers should support mindful abstraction through the introduction of a performance metaphor during pre-use training.

5. To support *far* transfer of learning, designers should,

   (a) For freehand gestures from Category A and C, support mindful abstraction through the introduction of a performance metaphor during pre-use training

   (b) For freehand gestures from Category B, support mindful abstraction through the introduction of a task metaphor during pre-use training (see below).

Finally, this further examination of the results suggest speculative recommendations for designers on supporting new users when transfer of learning fails to occur,

6. For *near* transfer of learning of freehand gestures (i.e. where new users know, or are prompted, that they can use previously learnt freehand gestures), when transfer of learning fails to occur from a designer perspective, participants "fall back" on a perceived suitable freehand gesture.

   (a) For freehand gestures from Category A and Category C, this "fall back" freehand gesture is, from a user perspective, perceived as less suitable compared to when the sought for freehand gesture is performed. This lower perception of suitability might prompt users into seeking, and allow designers to provide, additional support.

   (b) For freehand gestures from Category B however, the rating of the suitability of this "fall back" freehand gesture is similar to when the sought for freehand gesture is performed. However, the perceived suitability of these fall back freehand gestures decreases over time and might prompt users into seeking, and allow designers to provide, additional support.

7. For *far* transfer of learning of freehand gestures (i.e. where new users are unsure, or are not prompted, that they can use previously learnt freehand gestures) transfer of learning is particularly problematic for freehand gesture from Category B. Examination of the results from Study II suggested that, although participants presented with a task metaphor transfer less sought for freehand gestures than participants presented with a performance metaphor, transfer of learning fails to occur less when participant are presented with a task metaphor. Therefore, for freehand gestures from Category B, designers should support mindful abstraction through the introduction of a task metaphor during pre-use training.

6.3 Limitations and Future Work

Throughout this thesis we have highlighted potential limitations to the studies presented and how subsequent studies have addressed these limitations. In this section we address the wider limitations of this thesis and how future work might address these limitations.

One potential limitation to the generalisability of the results presented in this thesis is the effect of culture on the generation of freehand gestures. In particular, in supporting ease of learning and transfer of learning of freehand gestures we support learning to automaticity by drawing on the prior experience of those participants who generated the freehand gestures.

In all of the studies presented, participants were recruited from around the University of Bath and University of Glasgow. The nationalities of participants ranged from British, Greek and French to Brazilian and Chinese. However, all were fluent speakers of English and were undertaking, or had undertaken, further education in the UK.

It has been well documented that gestures produced as part of everyday human communication often differ between people from different cultures (see for example, Efron [1941]; McNeill [1992]; Kendon [2004]). Kita [2009] provides a review of gesture in human communication and identifies four factors which account for these observed differences. The first factor is culture specific conventions of emblem signs e.g. the OK sign or V for victory sign. The second is culture specific spatial cognition e.g. future forward and past back, or the passage of time indicated by a movement from left to right. The third is linguistic differences, that is, the lexical and syntactic differences between languages to for example, to express spatial information or movement. The fourth factor is culture specific gesture pragmatics e.g. politeness of gestures and the gesture space.

These factors suggest a number of challenges which future work should address, in particular during the generation of freehand gestures. As an example, factors one and three reflect the prior experience and linguistic resources available to participants to draw upon when generating freehand gestures. For example, a designer might wish to generate a freehand gesture for the task *Confirm*, which in certain cultures might elicit the OK sign as the most appropriate freehand gesture. However, in other cultures this sign might be better associated with a coin or the number zero.

Another significant challenge suggested by factor two, is the differences in how different cultures frame spatial relations with reference to the body. For example, the freehand gestures proposed in this thesis for *Move Forward* and *Move Back* perhaps reflect a cultural agreement that a movement from left to right indicates a transition forwards in time and right to left backwards in time. However, in other cultures an absolute frame of reference is used to understand temporal relations. In such a culture we might observe that the freehand gestures generated for *Move Forward* are predominately movements of the hand away from the body and *Move*

Back a movement towards the body. Similar cultural differences also exist to indicate spatial relationships.

Interestingly, the differences between cultures in the use of gesture space (factor four) has been used by Rehm et al. [2008] to automatically recognise the cultural background of a user. Rehm et al. propose that "with this information at hand, the behaviour of an interactive system can be adapted to culture-dependent patterns of interaction" [Rehm et al., 2008, pp 13].

Investigating the generation of multi-touch gestures by participants from different cultural backgrounds, Mauney et al. [2010] report that for direct manipulation tasks there is little difference in the gestures proposed. However, Mauney et al. did report significant differences between gestures generated for symbolic tasks e.g. delete, accept and back. This result is as would be expected considering the factors identified by Kita accounting for cultural differences in gestures.

However, Mauney et al. also report that participant prior experience with multi-touch gestures also significantly influences the gestures generated regardless of cultural background. That is, participants' with prior experience of using multi-touch devices often generate gestures already common to such devices. For example, pinching to zoom in and out as well as swiping to scroll up and down.

Again, this might be expected from the literature on transfer of learning. That is, from the prior experience with a similar device and performing a similar task, we would expect participants to transfer this prior knowledge to the generation of multi-touch gestures. Similarly, studying the gestures of Lithuanian Jewish and Sicilian immigrants to the USA, Efron [1941] reports that the traditional gestures observed in these communities often disappeared the more they assimilated into larger American culture. Future work should address this cultural difference in gestures as well as if these difference are reduced with the prevalence of systems using freehand gestures the main interaction technique.

Similarly, another potential limitation to the generalisability of the results presented in this thesis is the effect of handedness of new users. That is, does new user training on freehand gestures with the non-dominant hand effect retention, accuracy of performance and the transfer of learning of freehand gestures? As discussed in Chapter 3 Section 3.3.1, the literature on motor learning suggests that learning to perform a skill with one hand does not have a significantly detrimental effect on the performance of the same skill with the other hand. This generalisability of skill performance across both hands has been termed *intermanual* or *bimanual* transfer.

However, as Annett and Bischof [2013] highlight, for gestural interaction it is important to understand if this *intermanual* transfer is symmetric or asymmetric. Symmetric transfer is when transfer does not depend on the hand used during skill acquisition whereas asymmetric transfer does. In gestural interaction there is little research on *intermanual* transfer, in particular whether gesture learning is symmetric or asymmetric. Annett and Bischof [2013] investigate this challenge for stroke based gestural interactions and report that stroke based gestures transfer symmetrically with similar accuracy of performance being attained when performing stroke gestures with the opposite hand to that they were learnt. Furthermore, Annett and Bischof report no effect of the shape of the stroke gesture on the accuracy of performance.

Building on this research future work should investigate *intermanual* transfer of freehand gestures as well as whether freehand gestures transfer symmetrically or asymmetrically.

In the studies presented in this thesis, participants are trained on freehand gestures with learning and transfer of learning being assessed by asking participants to perform freehand gestures in response to tasks read out by the experimenter. One limitation to these studies is that participants do not perform freehand gestures on real devices or applications. Similarly, by not interacting with real devices or applications, participants are not provided with any feedback when performing a freehand gesture for example, a TV turning on or off, an image moving between devices or a document opening on a display.

The choice that participants not perform freehand gestures on real devices and applications was pragmatic. Implementation of freehand gesture recognition systems is a significant research challenge (e.g. Wu and Huang [1999]; Ramamoorthy et al. [2003]; Elmezain et al. [2009]) and beyond the scope of this thesis. Wizard-of-Oz studies might have been used, with the experimenter triggering actions on devices and application when participants perform a freehand gesture for a given task. However, the primary motivation for not providing real devices and applications was to focus participants on performing freehand gestures that would allow them to perform a task and not introduce potential constraints afforded or implied by specific devices or applications.

Future work should address this limitation. For example, does the performance of and feedback received when performing freehand gestures on real devices and applications change participant perception of the suitability of freehand gestures, the ease of learning of freehand gestures or the transfer of learning of freehand gestures?

Additionally, future work in this area might include further consideration of the scenarios and hence the tasks from which freehand gestures were generated. The augmented travel scenario used in this thesis focuses on tasks performed by users on devices and applications whilst travelling in a connected environment. However, this is one of many potential scenarios from which tasks might be extracted, although undoubtedly there are common tasks between these potential scenarios. Following the user studies described in this thesis, freehand gestures could be generated from identified tasks with ease of learning and ease of transfer of learning evaluated. From these studies, we can further refine the recommendations for designers detailed in Section 6.2.

Similarly, future work might focus on a specific scenario for example, at home, during surgery, in the car, for collaborative work systems etc. so as to identify a specific set of freehand gestures which are applicable to that scenario. These new freehand gestures sets could then be compared and contrasted. This comparison could suggest common freehand gestures for certain tasks as well as tasks where more specialised freehand gestures are more appropriate. Again, this comparison could help to further refine or elaborate the design recommendations detailed in Section 6.2.

One advantage to the generation of freehand gestures for specific scenarios would be to further examine the effect of supporting learning to automaticity and mindful abstraction on the transfer of learning of these freehand gestures to different scenarios (where commonality exists). For example, in the home scenario freehand gestures might have been selected for turn on and turn off which can control the lights, TV, stereo, air conditioning etc. In a different scenario these turn on and turn off freehand gestures might be used to turn on and off, a cars radio, a screen displaying an x-ray image of a patient, or a view of a CAD drawing being discussed or altered. Transfer of learning of freehand gestures learnt for the home scenario to the other scenarios could then be evaluated.

In addition to the scenarios used to generate freehand gestures, future work should include how freehand gestures might be performed in situations where, for example, both hands are not able to gesture or where performance of the freehand gesture is constrained. This might include situations where large movements might be considered inappropriate for example, in public spaces or packed train carriages. This future work might include freehand gesture generation studies where participants generate freehand gestures using one and two hands for a given task (similar to work by Wobbrock et al. [2009]). Alternatively, user studies might be conducted where participants are trained on a set of freehand gestures and asked to perform them using only one hand or whilst holding another object such as a cup of coffee or a bag.

Similarly, future work should include explorations of systems or form factors in which freehand gestures form the primary method of interaction. For example, Microsofts HoloLens[1] where interactive objects are overlaid on the users physical environment. Does the generation of freehand gestures differ substantially for such devices or systems compared to when generation is performed for imagined devices or applications? That is, does the specific device or system afford or imply what freehand gestures can be used and thus generated by participants?

A further limitation to the studies presented are that they are laboratory based. The literature on transfer of learning suggests a number of variables which may effect (either positively or negatively) the learners ability to transfer their learning to new situations. In particular, a change in context is highlighted as often producing a negative effect on transfer of learning (e.g. Lave and Wenger [1991]; Greeno et al. [1996]). Future work should examine the effect of a change in context on the transfer of learning of freehand gestures. For example, future work

[1] Microsoft HoloLens - `http://www.microsoft.com/microsoft-hololens/en-us` (last accessed June 2015)

might include examining the transfer of learning of freehand gestures learnt on devices such as HoloLens to similar interactions mediated outside of the HoloLens device.

Similarly, we have provided designer with recommendations on how to support the transfer of learning of freehand gestures through pre-use training. In the laboratory studies presented this was achieved through scripted videos and participants were trained on all freehand gestures in one training session. Future work might further explore how pre-use training can be delivered to new users and how this might be presented on devices or in applications with different specifications. Furthermore, future work should examine how users might be trained on new freehand gestures post initial training session. This future work should examine the effect this on-the-fly training has on the ease of learning and transfer of learning of freehand gestures.

Another avenue of future work should be to investigate how many different freehand gestures can be used to perform continuous interactions with devices and interactions. That is, in this thesis the studies presented ask participants to perform a previously learnt freehand gesture for a given task. Future work should explore how participants perform multiple freehand gestures to perform sets of tasks. For example, opening a music playlist, selecting a song, moving the audio output to dedicated speakers and turning up the volume.

Such experiments could provide insight into the physical performance of multiple freehand gestures, providing recommendations for designers on the features needed to be captured for recognition algorithms. Furthermore, such experiments could provide insights into challenges such as occlusion of hands or a gestural equivalent of elision. Elision is the omission of one or more sounds (such as a vowel, a consonant, or a whole syllable) in a word or phrase, producing a result that is easier for the speaker to pronounce. A gestural equivalent might be the omission of a freehand gesture in a sequence to perform a task. For example, opening a playlist and moving a song to the speakers where the audio of the song should be played i.e. elision of the song selection from the previous example.

Finally, at the start of this thesis we highlight that freehand gestures are just one of many different interaction techniques which can allow users to interact across devices and applications, for example in ubiquitous computing environments. One of the challenges of such environments is the need to support a range of different interaction techniques suitable for the users current needs and context. The work presented in this thesis contributes towards a better understanding of how freehand gestures can be used across different devices and applications. A future direction of this research is to explore the use of freehand gestures as part of a wider set of interaction techniques providing multi-modal interaction across devices and applications.

6.4 Conclusions

In this thesis we have investigated the transfer of learning of freehand gestures and answered our research question,

RQ: How can we support the transfer of learning of freehand gestures across different devices and applications?

Where, transfer of learning is the application of knowledge learnt in one context to a new context. For example, performing previously learnt freehand gestures to interact with different devices and applications.

A review of the literature highlights two mechanisms which if supported can facilitate transfer of learning - learning new material to automaticity and mindful abstraction Furthermore, the literature highlights that supporting both of these mechanisms improves both the learning and transfer of learning of new material. Building on this work a series of related studies were designed and conducted to,

1. Investigate how to support both mechanisms of transfer of learning for new users of freehand gestures

2. Experimentally test the observation made in the literature, that there are advantages to supporting both mechanisms of transfer of learning, examining the effect on both the learning and transfer of learning of freehand gestures

Addressing the former, this thesis has investigated how designers can draw on the users prior knowledge and experience to support learning to automaticity and how designers can use metaphor to support mindful abstraction. To support learning to automaticity, we have investigated how potential end users can generate freehand gestures for interaction across different devices and applications. To support mindful abstraction, we have investigated how designers can introduce metaphor during pre-use training.

Addressing the latter, we first investigated the effect of supporting both mechanisms of transfer of learning on the learning of freehand gestures. A user study reported a positive effect of supporting both mechanisms of transfer of learning on the ability of participants to correctly recall and perform freehand gestures. The results from this study contributed recommendations for designers on,

- How to support both mechanisms of transfer of learning for new users of freehand gestures

- Supporting the learning of freehand gestures for new users

- Metrics to allow designers to predict and evaluate the ease of learning of freehand gestures for new users.

Investigating the transfer of learning of freehand gestures, a series of related studies showed that new users do transfer previously learnt freehand gestures to new tasks designed for interaction across devices and applications. Moreover, the results showed a positive effect on the transfer of learning of freehand gestures by new users when both learning to automaticity and mindful abstraction is supported. Again, the results from these studies contributed recommendations for designers on,

- Supporting the transfer of learning of freehand gestures for new users
- Observations regarding the presence and absence of transfer of learning of freehand gestures for new users.
- Metrics to allow designers to predict the transfer of learning of freehand gestures by new users.

Overall, these recommendations answer our research question and contribute towards supporting the development of freehand gestures for interaction across devices and applications.

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Appendix A

Companion Materials - Chapter 3

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A.1 Companion Materials for the Freehand Gesture Generation Study

A.1.1 Scenario Used to Generate Tasks

Augmented Travelling - Barbaras trip to Blackpool

As a member of the University of the Third Age, Barbara has found a friend, Polly, who would like to join her on a day trip to Blackpool.

The two of them get together remotely to plan the day so that they can decide where to go and to buy tickets in advance. Barbara uses a touch sensitive flat screen device which projects images on the wall of her living room so that she can better see them. In addition to the image of the virtual keyboard on her device, she likes the fact that she feels specific parts of the virtual keyboard raise up, which dramatically helps the usability of the travel planning application that she and Polly are remotely sharing. Barbara buys virtual tickets online and is able to negotiate a discount by opting in to push advertising for the duration and location of the trip

On the morning of the big day a taxi comes by to pick up Barbara and then Polly to take them to the station. A screen on the back of the Taxi driver's seat begins to push relevant adverts regarding things they can do in Blackpool. An advert for some tea rooms in a hotel takes their fancy, and Barbara gestures to pull the information onto her mobile device so that they can use it later.

Once they've got to the station, the day is already hot. Inside the station there is an advert for Lipton's iced tea. Polly is feeling thirsty, so she gestures to the advert, and the details of a store in the station where she can buy a can of the drink appears on her mobile device. At the same time the back of her mobile becomes deliciously cold and she feels a rippling sensation like water droplets tumbling, which increases her desire for the drink. Just as she is buying the drink Barbara's phone begins to heat up, indicating that their train will soon be approaching and that they need to get to the platform.

Barbara's device senses that they are in the station and offers her options, including guided directions as to finding the train. Barbara selects this by squeezing her phone, until this option is highlighted. The phone projects arrows on the floor guiding them through the barriers, where they swipe their phones over a sensor to gain entry and register with railway services, and then onto the correct platform.

After a few minutes the train arrives on the platform, Barbara shakes her phone to reactivate it, and points it at the side of the carriage. Arrows are projected on the side of the train to guide them to the correct carriage. They have to get on board in a hurry, and since the train is too crowded to project, Barbara relies on temperature as a means of guiding them. They start off in the wrong direction, and her phone goes cold, when she starts going in the correct direction the phone gets warm.

They recognise their seats, as the setback display is displaying their names and after they sit down they see a selection of their favourite programmes and games advertised on the screens, as well as further adverts regarding things to do in Blackpool. They decide to play a game of backgammon, for a small fee. Due to the size of the screens, they decide to split the backgammon board between their setback displays and their mobile devices. They can also feel the pieces on their displays.

As they approach Blackpool, Barbara's phone begins to feel warm, notifying them that they are near their destination. Once they have got off the train and exited the station, Barbara uses a tactile map on her mobile device to find the way to the tram stop, as the sun is too bright too allow directions to be clearly projected on to the pavement.

They take the tram along the seafront and get off at the pier, where they are guided to the site of the Gala Bingo, where they had planned to spend a couple of hours. To their disappointment the Gala was closed for renovations, but fortunately their trip adviser is able to advise them and guide them using a tactile map to the Mecca, which provides a fine alternative.

Following the bingo, they are guided to Grand Metropol, whose details they took when they were in the taxi, for tea and following that to the Opera House Theatre where they had arranged to see a show. They were now able to use directions projected from Barbara's phone on to the pavement to guide their way.

At the theatre, once they have swiped in at the gates, using their phones (and repurchased e-tickets), the projected images then guide them to their seats. During the show, Polly, who is somewhat hard of hearing, is able to see subtitles streamed to her mobile device.

The show is a great success, but at its end they are conscious that they need to get back to the railway station quickly to catch the last train. They decide to take a taxi, and register to share one through the theatre's own services application, which Barbara easily access on a screen in the theatre lobby. She and Polly easily find the taxi that they have booked to share, by projecting Barbara's phone against the taxis in the rank, until they have found the right one.

Acknowledgements

This scenario was written and edited by Ben Eaton[1] with contributions from the Universities of Bath, Bristol, Glasgow and the LSE.

[1] `http://www2.lse.ac.uk/management/research/phd-students/beaton.aspx`

A.1.2 Tasks Presented to Participants

Table A.1: The 52 Interaction and User Tasks Presented to Participants in the Freehand Gesture Generation Study

Task No.	Task	Task Type
1	Close	Interaction Task
2	Close a document	User Task
3	Close an application	User Task
4	Delete	Interaction Task
5	Delete a piece of text	User Task
6	Delete an image	User Task
7	Drop	Interaction Task
8	Drop some media	User Task
9	Go back	Interaction Task
10	Go back to the previous image	User Task
11	Go to	Interaction Task
12	Go to an image	User Task
13	Go to your media	User Task
14	Move a document from one device to another	User Task
15	Move an application from one device to another	User Task
16	Move back	Interaction Task
17	Move back in the video a few seconds	User Task
18	Move forward	Interaction Task
19	Move forward in the video a few seconds	User Task
20	Open	Interaction Task
21	Open a document	User Task
22	Open an application	User Task
23	Pick up	Interaction Task
24	Pick up some media	User Task
25	Play	Interaction Task
26	Play a video	User Task
27	Search	Interaction Task
28	Search a video	User Task
29	Search for a piece of text	User Task
30	Select a TV	User Task
31	Select	Interaction Task
32	Select a button	User Task
33	Select a piece of text	User Task
34	Select an advert	User Task

Continued on next page

Table A.1 – *Continued from previous page*

Task No.	Task	Task Type
35	Show me	Interaction Task
36	Show me information about this cafe	User Task
37	Show me my location	User Task
38	Show me my trains platform	User Task
39	Show me on that wall	User Task
40	Show me on this TV	User Task
41	Stop	Interaction Task
42	Stop a video	User Task
43	Turn off	Interaction Task
44	Turn off a TV	User Task
45	Turn on	Interaction Task
46	Turn on a TV	User Task
47	Zoom in	Interaction Task
48	Zoom in to a image	User Task
49	Zoom in to a map	User Task
50	Zoom out	Interaction Task
51	Zoom out of a map	User Task
52	Zoom out of an image	User Task

A.1.3 Accompanying Materials for the Freehand Gesture Generation Study

Consent Form

Gesture Study

Thank you for taking part in this study! This study aims to gain an insight into the gestures people make in order to perform different actions. You will be read aloud an action and it is your job to make a gesture that you think corresponds to that action.

The study will take approximately 40 minutes. You can withdraw at any time before, during or after the study. During the study you will be filmed. This video data will be used to compare gestures across participants.

Data extracted from this video will be anonymous. However, for use in presentations your video cannot easily be anonymised. So, if you are willing to allow your video to be shown in presentations then please indicate below.

1. ☐ I have read and understood the study description above and understand what will happen during the study.
2. ☐ I understand that I can withdraw at any time before, during or after the study
3. ☐ I agree for video data to be taken and used as part of the study
4. ☐ Any video of me CAN be used in presentations without anonymisation

Name: .... Age: ....

First Language: ....

Signature: .... Date: ....

A.2 Companion Materials for the Follow Up Ease of Learning Study

A.2.1 Accompanying Materials for the Follow Up Ease of Learning Study

Information Sheet and Consent Form

Gesture Study

Thank you for taking part in this study! The aim of the study is to gain an insight into the technical and usability aspects of gestural interaction. The study is divided into four parts

1. Training: in this part of the study you will be asked to perform a specific gesture in front of the BumbleBee camera. You will be asked to perform each gesture 10 times.

2. Task 1: after training you will be read aloud an action and it is your job to make a gesture that you think corresponds to that action. In this part the gestures might not be the ones you have learned in training and you are encouraged to be as creative as possible

3. Task 2: following task 1 you will be again be read aloud an action however, this time you will be asked to only use the gestures you have learned in the training part of the study

4. Questionnaire: finally, at the end of the study you will be asked to complete a questionnaire

The study will take approximately 40 minutes. You can withdraw at any time before, during or after the study. During the study we would like to film you. This video may be used in presentations. Anonymisation of video is not easy so, if you are willing to filmed and for your video to be shown in presentations then please indicate below.

1. ☐ I have read and understood the study description above and understand what will happen during the study.

2. ☐ I understand that I can withdraw at any time before, during or after the study

3. ☐ I agree for data to be taken and used as part of the study

4. ☐ Any video of me CAN be used in presentations without anonymisation

Age: ....

Name: ....

Signature: .... Date: ....

Questionnaire

Questionnaire

The questions below ask you to give a rating from strongly disagree to strongly agree. The questions asked are focused on the gesture you were trained on and the tasks where you used these gestures.

1. I think that I would like to this type of gestural interaction frequently

Strongly disagree				Strongly agree
1.	2.	3.	4.	5.

2. I found the gestures unnecessarily complex

Strongly disagree				Strongly agree
1.	2.	3.	4.	5.

3. I thought the gestures were easy to use

Strongly disagree				Strongly agree
1.	2.	3.	4.	5.

4. I would imagine that most people would learn these gestures very quickly

Strongly disagree				Strongly agree
1.	2.	3.	4.	5.

5. I felt very confident using the gestures

Strongly disagree				Strongly agree
1.	2.	3.	4.	5.

For each gesture your were trained on please give a rating for how much you felt it action of the gesture related to the function of the gesture i.e. did the action of the select gesture feel right?

Gesture	1																			20
Close																				
Delete																				
Drop																				
Move Back																				
Move Forward																				
Open																				
Pick Up																				
Search																				
Select																				
Show Me																				
Zoom In																				
Zoom Out																				

Are there any other comments you wish to make?

Appendix B

Companion Materials - Chapter 4

B.1 Accompanying Materials for the Metaphor and Learning Study 301

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B.1 Accompanying Materials for the Metaphor and Learning Study

B.1.1 Information Sheet - No Metaphor Condition

Information Sheet

Project: A Design Tool for Assessing Potential Gestures for Interaction in Pervasive Environments

Researcher: Michael Wright

You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.

The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study will be conducted over the course of 5 weeks. An outline of the study is shown below. In the first week you will complete parts 1 to 4. In the remaining 4 weeks you will complete parts 3 and 4 only.

1. Training: in this part of the study you will be trained on a set of gestures. You will be shown a video for each gesture. The video contains (i) a description of how to perform the gesture and (ii) a demonstration of the gesture.

   Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

2. Questionnaire 1: after training you will be asked to complete a questionnaire.

3. Task: in this part of the study you will be told the name of a gesture. It is your task to perform that gesture.

4. Questionnaire 2: finally, at the end of the study, you will be asked to complete a second questionnaire.

The study will last for 5 weeks - one session per week lasting for approximately 40 minutes. You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published in some other research publications. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed. The research is jointly funded by MobileVCE and EPSRC. MobileVCE - A Virtual Centre for Excellence is funded by subscriptions from individual members of Mobile and Telecommunications industries. All research carried out is made freely available to all subscribers (unless individually contracted).

B.1.2 Information Sheet - Task and Performance Metaphor Conditions

Information Sheet

Project: A Design Tool for Assessing Potential Gestures for Interaction in Pervasive Environments
Researcher: Michael Wright
You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.
The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study will be conducted over the course of 5 weeks. An outline of the study is shown below. In the first week you will complete parts 1 to 4. In the remaining 4 weeks you will complete parts 3 and 4 only.

1. Training: in this part of the study you will be trained on a set of gestures. The video contains (i) a description of the metaphor for the gesture, (ii) a description of how to perform the gesture and (iii) a demonstration of the gesture.

   Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

2. Questionnaire 1: after training you will be asked to complete a questionnaire.

3. Task: in this part of the study you will be told the name of a gesture. It is your task to perform that gesture.

4. Questionnaire 2: finally, at the end of the study, you will be asked to complete a second questionnaire.

The study will last for 5 weeks - one session per week lasting for approximately 40 minutes. You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published in some other research publications. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed. The research is jointly funded by MobileVCE and EPSRC. MobileVCE - A Virtual Centre for Excellence is funded by subscriptions from individual members of Mobile and Telecommunications industries. All research carried out is made freely available to all subscribers (unless individually contracted).

B.1.3 Consent Form - All Conditions

Consent Form

Project: A Design Tool for Assessing Potential Gestures for Interaction in Pervasive Environments

Researcher: Michael Wright

1. ☐ I confirm I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. ☐ I understand that my permission is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.
3. ☐ I agree to take part in the above study.
4. ☐ I agree for video data to be taken and used as part of the study
5. ☐ Any video of me CAN be used in presentations without anonymisation
6. ☐ I would like to receive a summary sheet of the experimental findings

if you wish a summary, please leave an email address ....

Name:.....................................Age: ....

Signature: .... Date: ....

Name of Researcher: ....

Signature: .... Date: ....

B.1.4 Questionnaire 1 - No Metaphor Condition

Questionnaire 1

1. For each gesture you were trained on please indicate how familiar you are with the gesture (1 is not familiar at all and 10 very familiar) and from where you are familiar with it?

Gesture	1	2	3	4	5	6	7	8	9	10	**From where?**
Move Forward											
Open											
Turn On											
Play											
Move											
Move Back											
Open											
Go To											
Close											
Zoom Out											
Pick Up											
Drop											
Turn Off											
Search											
Delete											
Stop											
Select											
Zoom In											
Show Me											

2. For each gesture you were trained on please tell how you remembered the gesture?

Gesture	**How did you remember the gesture?**
Move Forward	
Open	
Turn On	
Play	
Move	
Move Back	
Go To	
Close	
Zoom Out	
Pick Up	
Drop	
Turn Off	
Search	
Delete	
Stop	
Select	
Zoom In	
Show Me	

3. For each gesture you were trained on please indicate how well you thought the gesture matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

B.1.5 Questionnaire 1 - Task and Performance Metaphor Conditions

Questionnaire 1

1. For each gesture you were trained on please indicate how familiar you are with the gesture (1 is not familiar at all and 10 very familiar) and from where you are familiar with it?

Gesture	1	2	3	4	5	6	7	8	9	10	**From where?**
Move Forward											
Open											
Turn On											
Play											
Move											
Move Back											
Open											
Go To											
Close											
Zoom Out											
Pick Up											
Drop											
Turn Off											
Search											
Delete											
Stop											
Select											
Zoom In											
Show Me											

2. For each gesture you were trained on please indicate how well you thought the metaphor matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

3. For each gesture you were trained on please indicate how well you thought the metaphor matched the gesture (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

4. For each gesture you were trained on please indicate how well you thought the gesture matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

B.1.6 Questionnaire 2 - No Metaphor Condition

Questionnaire 2

1. For each gesture you were trained on please tell us how you remembered the gesture?

Gesture	**How did you remember the gesture?**
Move Forward	
Open	
Turn On	
Play	
Move	
Move Back	
Go To	
Close	
Zoom Out	
Pick Up	
Drop	
Turn Off	
Search	
Delete	
Stop	
Select	
Zoom In	
Show Me	

2. For each gesture you were trained on please indicate how well you thought the gesture matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

B.1.7 Questionnaire 2 - Task and Performance Metaphor Conditions

Questionnaire 2

1. For each gesture you were trained on please indicate how well you thought the metaphor matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

2. For each gesture you were trained on please indicate how well you thought the metaphor matched the gesture (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

3. For each gesture you were trained on please indicate how well you thought the gesture matched the task (1 not well matched and 10 very well matched)

Gesture	1	2	3	4	5	6	7	8	9	10
Move Forward										
Open										
Turn On										
Play										
Move										
Move Back										
Open										
Go To										
Close										
Zoom Out										
Pick Up										
Drop										
Turn Off										
Search										
Delete										
Stop										
Select										
Zoom In										
Show Me										

4. For each gesture you were trained on please tell how you remembered the gesture?

Gesture	**How did you remember the gesture?**
Move Forward	
Open	
Turn On	
Play	
Move	
Move Back	
Go To	
Close	
Zoom Out	
Pick Up	
Drop	
Turn Off	
Search	
Delete	
Stop	
Select	
Zoom In	
Show Me	

Appendix C

Companion Materials - Chapter 5

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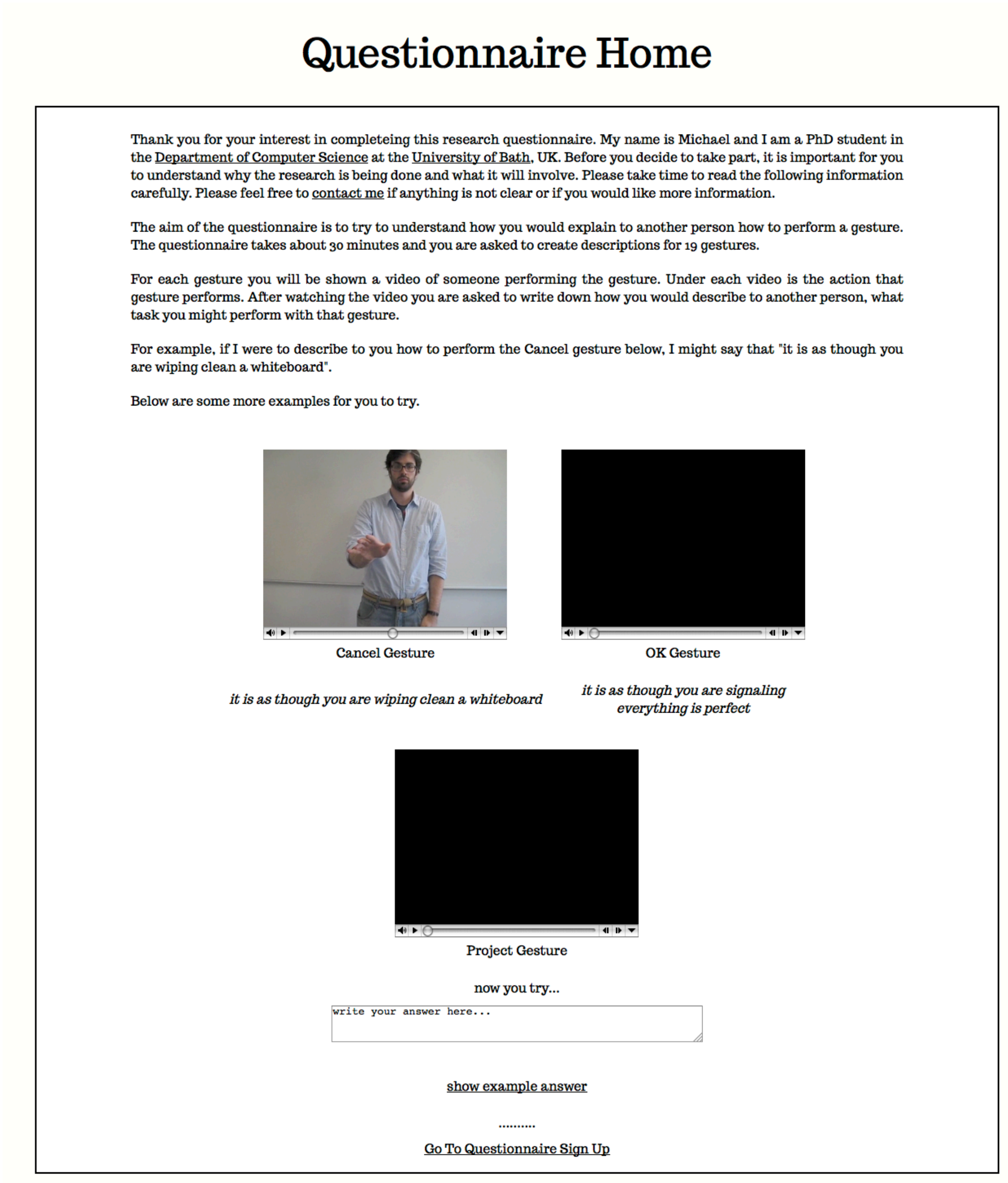
C.1 Metaphor Generation Online Questionnaire

C.1.1 Metaphor Generation Online Questionnaire 1

Introduction Page: Task Metaphor Generation Participants



Questionnaire Home

Thank you for your interest in completeing this research questionnaire. My name is Michael and I am a PhD student in the Department of Computer Science at the University of Bath, UK. Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please feel free to contact me if anything is not clear or if you would like more information.

The aim of the questionnaire is to try to understand how you would explain to another person how to perform a gesture. The questionnaire takes about 30 minutes and you are asked to create descriptions for 19 gestures.

For each gesture you will be shown a video of someone performing the gesture. Under each video is the action that gesture performs. After watching the video you are asked to write down how you would describe to another person, what task you might perform with that gesture.

For example, if I were to describe to you how to perform the Cancel gesture below, I might say that "it is as though you are wiping clean a whiteboard".

Below are some more examples for you to try.

Cancel Gesture

it is as though you are wiping clean a whiteboard

OK Gesture

it is as though you are signaling everything is perfect

Project Gesture

now you try...

write your answer here...

show example answer

....

Go To Questionnaire Sign Up

Introduction Page: Performance Metaphor Generation Participants

Questionnaire Home

Thank you for your interest in completeing this research questionnaire. My name is Michael and I am a PhD student in the Department of Computer Science at the University of Bath, UK. Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please feel free to contact me if anything is not clear or if you would like more information.

The aim of the questionnaire is to try to understand how you would explain to another person how to perform a gesture. The questionnaire takes about 30 minutes and you are asked to create descriptions for 19 gestures.

For each gesture you will be shown a video of someone performing the gesture. Under each video is the action that gesture performs. After watching the video you are asked to write down how you would describe to another person, how to perform the gesture based on its overall shape and movement.

For example, if I were to describe to you how to perform the Cancel gesture below, I might say that "it looks like waving your hand".

Below are some more examples for you to try.

Cancel Gesture

it looks like waving your hand

OK Gesture

it looks like you are pinching something with your thumb and index finger

Project Gesture

now you try...

write your answer here...

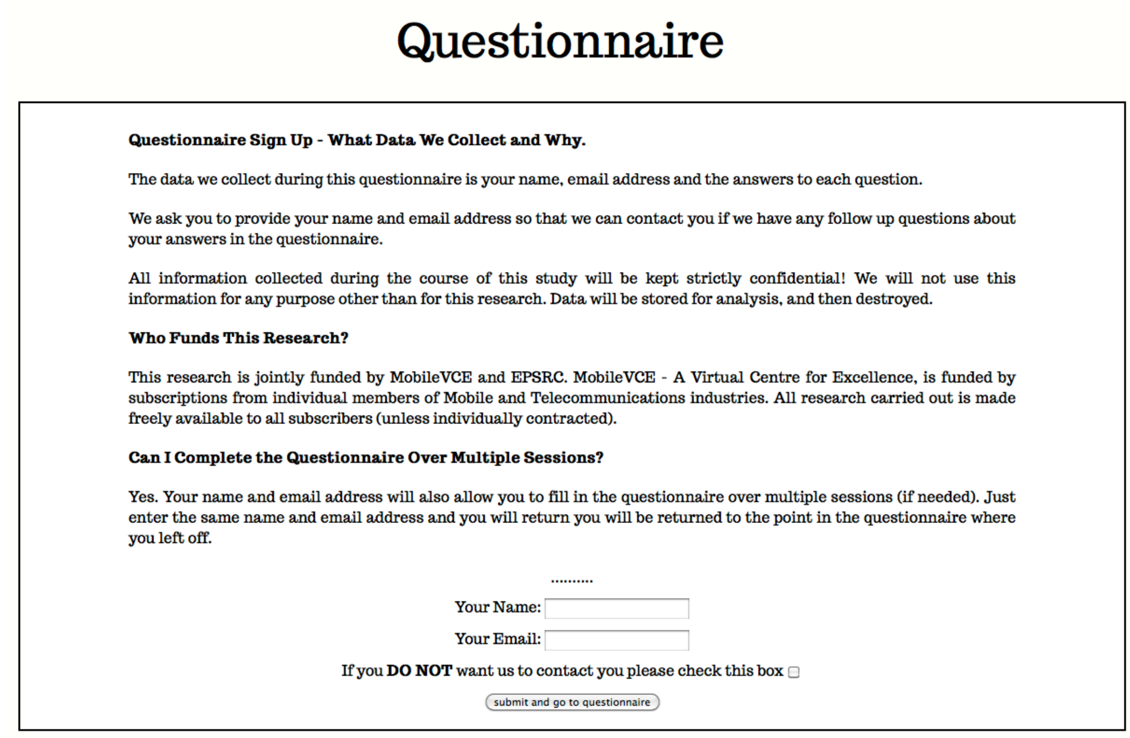
it looks like you are throwing something away with both hands

show example answer

....

Go To Questionnaire Sign Up

Consent Form: All Participants



Questionnaire

Questionnaire Sign Up - What Data We Collect and Why.

The data we collect during this questionnaire is your name, email address and the answers to each question.

We ask you to provide your name and email address so that we can contact you if we have any follow up questions about your answers in the questionnaire.

All information collected during the course of this study will be kept strictly confidential! We will not use this information for any purpose other than for this research. Data will be stored for analysis, and then destroyed.

Who Funds This Research?

This research is jointly funded by MobileVCE and EPSRC. MobileVCE - A Virtual Centre for Excellence, is funded by subscriptions from individual members of Mobile and Telecommunications industries. All research carried out is made freely available to all subscribers (unless individually contracted).

Can I Complete the Questionnaire Over Multiple Sessions?

Yes. Your name and email address will also allow you to fill in the questionnaire over multiple sessions (if needed). Just enter the same name and email address and you will return you will be returned to the point in the questionnaire where you left off.

....

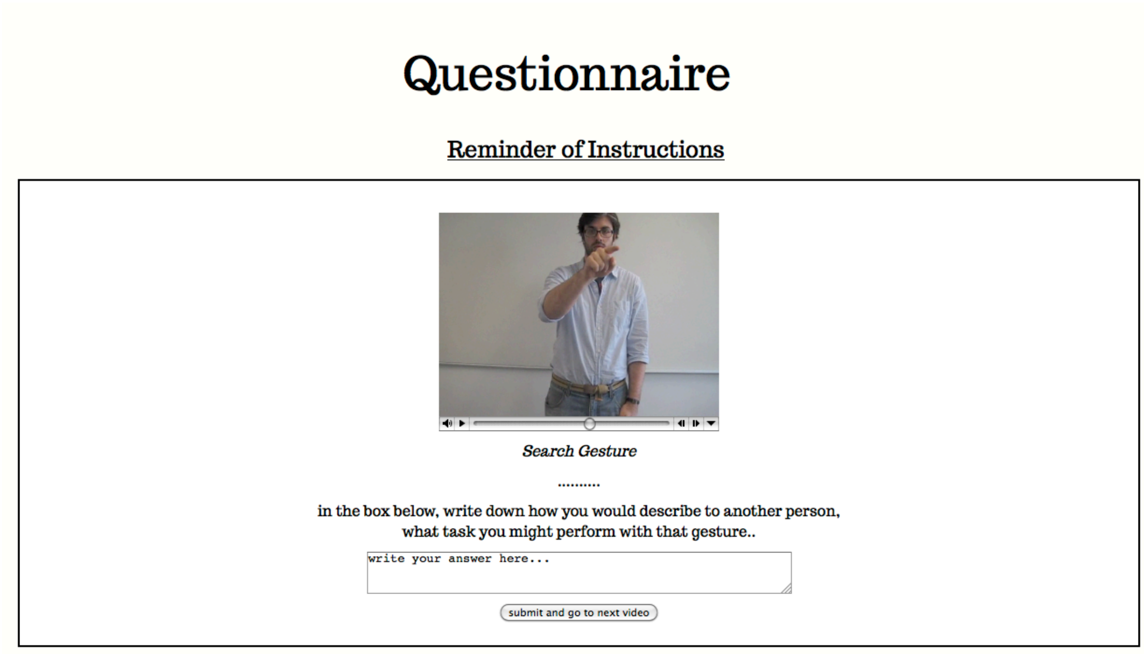
Your Name:

Your Email:

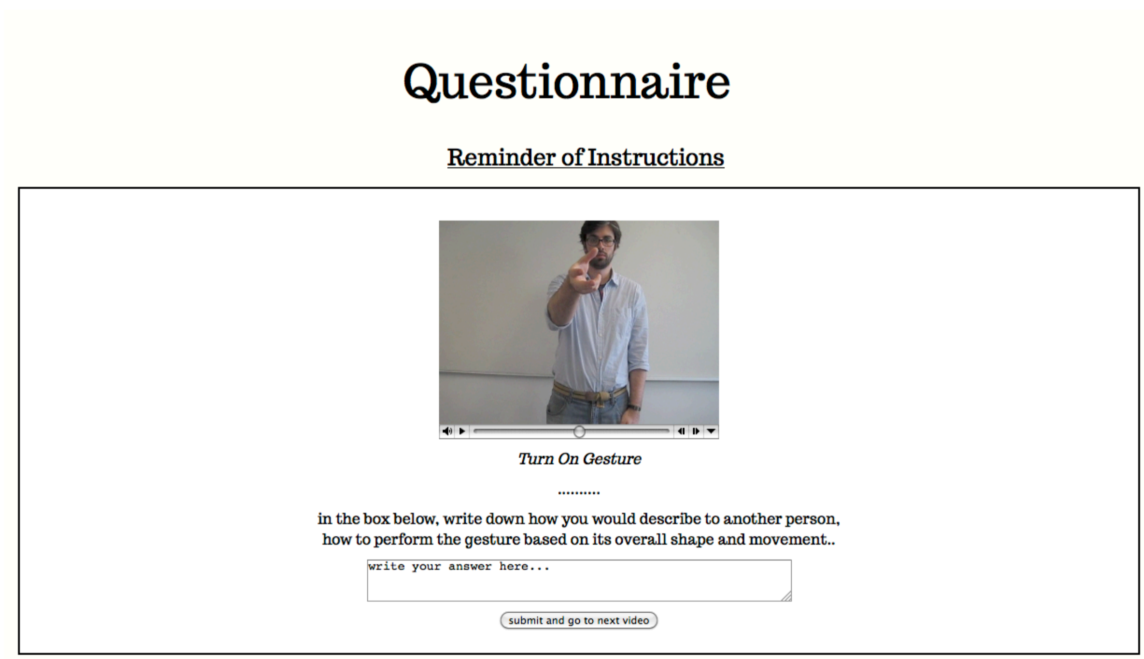
If you **DO NOT** want us to contact you please check this box

submit and go to questionnaire

Metaphor Form: Task Metaphor Generation Participants



Metaphor Form: Performance Metaphor Generation Participants



Questionnaire Completed: All Participants

Completed!

Thank you for completing the questionnaire!

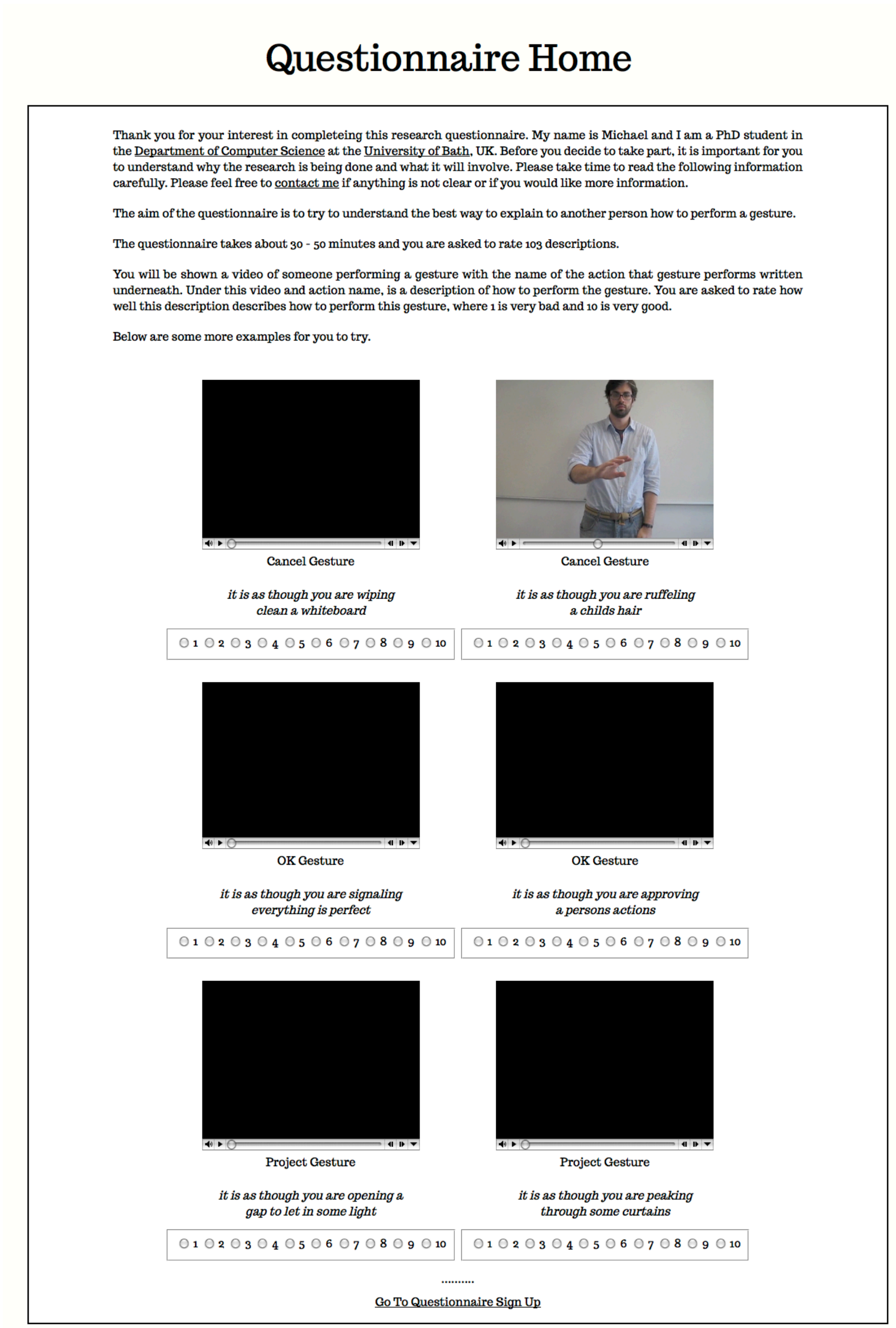
The information you have submitted will now be analysed as part of my research.

If you have any questions or queries please do not hesitate to contact me.

You should now close this window to exit the questionnaire.

C.1.2 Metaphor Generation Online Questionnaire 2

Introduction Page: Task Metaphor Generation Participants



Questionnaire Home

Thank you for your interest in completeing this research questionnaire. My name is Michael and I am a PhD student in the Department of Computer Science at the University of Bath, UK. Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please feel free to contact me if anything is not clear or if you would like more information.

The aim of the questionnaire is to try to understand the best way to explain to another person how to perform a gesture.

The questionnaire takes about 30 - 50 minutes and you are asked to rate 103 descriptions.

You will be shown a video of someone performing a gesture with the name of the action that gesture performs written underneath. Under this video and action name, is a description of how to perform the gesture. You are asked to rate how well this description describes how to perform this gesture, where 1 is very bad and 10 is very good.

Below are some more examples for you to try.

Cancel Gesture

it is as though you are wiping clean a whiteboard

1 2 3 4 5 6 7 8 9 10

Cancel Gesture

it is as though you are ruffeling a childs hair

1 2 3 4 5 6 7 8 9 10

OK Gesture

it is as though you are signaling everything is perfect

1 2 3 4 5 6 7 8 9 10

OK Gesture

it is as though you are approving a persons actions

1 2 3 4 5 6 7 8 9 10

Project Gesture

it is as though you are opening a gap to let in some light

1 2 3 4 5 6 7 8 9 10

Project Gesture

it is as though you are peaking through some curtains

1 2 3 4 5 6 7 8 9 10

....

Go To Questionnaire Sign Up

Introduction Page: Performance Metaphor Generation Participants

Questionnaire Home

Thank you for your interest in completeing this research questionnaire. My name is Michael and I am a PhD student in the Department of Computer Science at the University of Bath, UK. Before you decide to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please feel free to contact me if anything is not clear or if you would like more information.

The aim of the questionnaire is to try to understand the best way to explain to another person how to perform a gesture.

The questionnaire takes about 30 - 50 minutes and you are asked to rate 83 descriptions.

You will be shown a video of someone performing a gesture with the name of the action that gesture performs written underneath. Under this video and action name, is a description of how to perform the gesture. You are asked to rate how well this description describes how to perform this gesture, where 1 is very bad and 10 is very good.

Below are some more examples for you to try.

Cancel Gesture

it looks like waving your hand

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ◉ 9 ○ 10

Cancel Gesture

it looks like dusting a shelf

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

OK Gesture

it looks like you are pinching something with your thumb and index finger

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

OK Gesture

it looks like you are making an "O" shape

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Project Gesture

it looks like you are throwing something away with both hands

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Project Gesture

it looks like you are showing you have nothing in your hands

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

....

Go To Questionnaire Sign Up

Consent Form: All Participants

Questionnaire

Questionnaire Sign Up - What Data We Collect and Why.

The data we collect during this questionnaire is your name, email address and the answers to each question.

We ask you to provide your name and email address so that we can contact you if we have any follow up questions about your answers in the questionnaire.

All information collected during the course of this study will be kept strictly confidential! We will not use this information for any purpose other than for this research. Data will be stored for analysis, and then destroyed.

Who Funds This Research?

This research is jointly funded by MobileVCE and EPSRC. MobileVCE - A Virtual Centre for Excellence, is funded by subscriptions from individual members of Mobile and Telecommunications industries. All research carried out is made freely available to all subscribers (unless individually contracted).

Can I Complete the Questionnaire Over Multiple Sessions?

Yes. Your name and email address will also allow you to fill in the questionnaire over multiple sessions (if needed). Just enter the same name and email address and you will return you will be returned to the point in the questionnaire where you left off.

....

Your Name:

Your Email:

If you **DO NOT** want us to contact you please check this box

submit and go to questionnaire

Rating Form: Task Metaphor Generation Participants

Questionnaire

Reminder of Instructions

1 / 103

Turn Off Gesture

"as though you are turning an imaginary dial clockwise."

....

How well does this description describe how to perform this gesture?

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

submit and go to next description

Rating Form: Performance Metaphor Generation Participants

Questionnaire

Reminder of Instructions

1 / 83

Pick Up Gesture

"looks like grabbing something and moving it upward"

....

How well does this description describe how to perform this gesture?

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

submit and go to next description

Questionnaire Completed: All Participants

Completed!

Thank you for completing the questionnaire!

The information you have submitted will now be analysed as part of my research.

If you have any questions or queries please do not hesitate to contact me.

You should now close this window to exit the questionnaire.

C.2 Accompanying Materials for Metaphor and Transfer Study I

C.2.1 Information Sheet - No Metaphor Condition

Information Sheet

Project: Exploring Gestural Interaction Across Devices, Services and Contexts
Researcher: Michael Wright

You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.

The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study is broken in to two parts. All participants will complete part 1 however, not all participants will be selected for part 2. Part 1 of the study will take place over two sessions lasting approximately 1 hour each. Part 2 of the study will take place over a further two sessions lasting approximately 30 minutes each.

An outline of the study is shown below.

Part 1 Weeks 1 and 2:
Week 1 Training Videos: in this part of the study you will be trained on a set of gestures. You will be shown a video demonstrating a gesture used to perform a task. The video contains (i) the task (ii) a description of how to perform the gesture and (iii) a demonstration of the gesture.

Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

After you have correctly demonstrated the gesture you will be asked to rate your prior familiarity with the gesture (and from where) as well as the fit of the gesture to the task.
Week 1 Task: following training you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture. After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.
Week 2 Task: you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture.

After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Part 2 Weeks 3 and 4:
You will be read aloud a new task and it is your job to perform the gesture, from those you were trained on, which would perform that task. No feedback is given during this part of the study. After you have performed the gesture you will be asked to rate the fit of the gesture to the task.

You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed.

C.2.2 Information Sheet - Task and Performance Metaphor Conditions

Information Sheet

Project: Exploring Gestural Interaction Across Devices, Services and Contexts
Researcher: Michael Wright

You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.

The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study is broken in to two parts. All participants will complete part 1 however, not all participants will be selected for part 2. Part 1 of the study will take place over two sessions lasting approximately 1 hour each. Part 2 of the study will take place over a further two sessions lasting approximately 30 minutes each.

An outline of the study is shown below.

Part 1 Weeks 1 and 2:

Week 1 Training Videos: in this part of the study you will be trained on a set of gestures. You will be shown a video demonstrating a gesture used to perform a task. The video contains (i) the task (ii) a metaphor for the gesture (iii) a description of how to perform the gesture and (iv) a demonstration of the gesture.

Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

After you have correctly demonstrated the gesture you will be asked to rate your prior familiarity with the gesture (and from where) as well as the fit of the gesture to the task.

Week 1 Task: following training you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture. After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Week 2 Task: you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture.

After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Part 2 Weeks 3 and 4:
You will be read aloud a new task and it is your job to perform the gesture, from those you were trained on, which would perform that task. No feedback is given during this part of the study. After you have performed the gesture you will be asked to rate the fit of the gesture to the task.

You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed.

C.2.3 Consent Form - All Conditions

Consent Form

Project: Exploring Gestural Interaction Across Devices, Services and Contexts

Researcher: Michael Wright

1. ☐ I confirm I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. ☐ I understand that my permission is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.
3. ☐ I agree to take part in the above study.
4. ☐ I agree for video data to be taken and used as part of the study
5. ☐ Any video of me CAN be used in presentations without anonymisation
6. ☐ I would like to receive a summary sheet of the experimental findings

if you wish a summary, please leave an email address ....

Name:.....................................Age: ....

Signature: .... Date: ....

Name of Researcher: ....

Signature: .... Date: ....

C.2.4 Training Questionnaire - All Conditions

After the participant had correctly demonstrated the freehand gesture to the experimenter they were asked to rate their prior familiarity with the freehand gesture, give details of this familiarity as well as rate the fit of the freehand gesture to the task. Participants were asked the following questions for each of the 18 freehand gestures they were trained on.

Questionnaire

	(i) Please indicate how familiar you are with the gesture (1 is not familiar at all and 7 very familiar) 1 2 3 4 5 6 7 ***(i) (ii) From where you are familiar with it?*** ***(i) How well do you think the gesture matched the task (1 not well matched and 7 very well matched)*** 1 2 3 4 5 6 7

C.2.5 Learning Assessment Questionnaire - All Conditions

After the participant had correctly performed the freehand gesture they were asked to rate the fit of the freehand gesture to the task. Participants were asked the following question for each of the 18 freehand gestures they were tested on.

Questionnaire

	How well do you think the gesture matched the task (1 not well matched and 7 very well matched)						
	1	2	3	4	5	6	7

C.2.6 Transfer Questionnaire - All Conditions

After the participant had performed a freehand gesture they were asked to rate the fit of the freehand gesture to the task. Participants were asked the following question for each of the 36 new *Directed* and *Open Ended* user tasks presented.

Questionnaire

	How well do you think the gesture matched the task (1 not well matched and 7 very well matched)						
	1	2	3	4	5	6	7

C.3 Accompanying Materials for Metaphor and Transfer Study II

C.3.1 Information Sheet - No Metaphor Condition

Information Sheet

Project: Exploring Gestural Interaction Across Devices, Services and Contexts
Researcher: Michael Wright

You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.

The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study is broken in to two parts. All participants will complete part 1 however, not all participants will be selected for part 2. Part 1 of the study will take place over two sessions lasting approximately 1 hour each. Part 2 of the study will take place over a further two sessions lasting approximately 30 minutes each.

An outline of the study is shown below.

Part 1 Weeks 1 and 2:
Week 1 Training Videos: in this part of the study you will be trained on a set of gestures. You will be shown a video demonstrating a gesture used to perform a task. The video contains (i) the task (ii) a description of how to perform the gesture and (iii) a demonstration of the gesture.

Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

After you have correctly demonstrated the gesture you will be asked to rate your prior familiarity with the gesture (and from where) as well as the fit of the gesture to the task.
Week 1 Task: following training you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture. After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.
Week 2 Task: you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture.

After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Part 2 Weeks 3 and 4:
You will be read aloud a new task and it is your job to perform a gesture which you feel would best perform that task. No feedback is given during this part of the study. After you have performed the gesture you will be asked to rate the fit of the gesture to the task.

You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed.

C.3.2 Information Sheet - Task and Performance Metaphor Conditions

Information Sheet

Project: Exploring Gestural Interaction Across Devices, Services and Contexts
Researcher: Michael Wright

You are invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Ask me if anything is not clear or if you would like more information.

The aim of the study is to gain an insight into the usability aspects of gestural interaction. The study is broken in to two parts. All participants will complete part 1 however, not all participants will be selected for part 2. Part 1 of the study will take place over two sessions lasting approximately 1 hour each. Part 2 of the study will take place over a further two sessions lasting approximately 30 minutes each.

An outline of the study is shown below.

Part 1 Weeks 1 and 2:

Week 1 Training Videos: in this part of the study you will be trained on a set of gestures. You will be shown a video demonstrating a gesture used to perform a task. The video contains (i) the task (ii) a metaphor for the gesture (iii) a description of how to perform the gesture and (iv) a demonstration of the gesture.

Once the video finishes you will be asked to demonstrate the gesture to the researcher 10 times. You must correctly demonstrate the gesture 10 times consecutively. If you make a mistake you will be shown the video again and asked to try again.

After you have correctly demonstrated the gesture you will be asked to rate your prior familiarity with the gesture (and from where) as well as the fit of the gesture to the task.

Week 1 Task: following training you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture. After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Week 2 Task: you will be read aloud a task and it is your job to perform the corresponding gesture. You will be told if the gesture is correct. If you make the wrong gesture you will be shown the video again and asked to perform the correct gesture.

After you have correctly performed the gesture you will be asked to rate the fit of the gesture to the task.

Part 2 Weeks 3 and 4:
You will be read aloud a new task and it is your job to perform a gesture which you feel would best perform that task. No feedback is given during this part of the study. After you have performed the gesture you will be asked to rate the fit of the gesture to the task.

You can withdraw at any time before, during or after the study. We will collect the following data of you during the experiment,

- A video recording of the session
- Observations that we make during the experiment
- Your responses to questionnaires and to discussions about the gestures

All information collected about you during the course of this study will be kept strictly confidential. The results of the evaluation may also be published. You will be identified by an ID number and all information about you will have your name and contact details removed so that you cannot be recognised from it. Data will be stored for analysis, and then destroyed.

C.3.3 Consent Form - All Conditions

Consent Form

Project: Exploring Gestural Interaction Across Devices, Services and Contexts

Researcher: Michael Wright

1. ☐ I confirm I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. ☐ I understand that my permission is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.
3. ☐ I agree to take part in the above study.
4. ☐ I agree for video data to be taken and used as part of the study
5. ☐ Any video of me CAN be used in presentations without anonymisation
6. ☐ I would like to receive a summary sheet of the experimental findings

if you wish a summary, please leave an email address . . . .

Name:. . . . . Age: . . . .

Signature: . . . . Date: . . . .

Name of Researcher: . . . .

Signature: . . . . Date: . . . .

C.3.4 Training Questionnaire - All Conditions

After the participant had correctly demonstrated the freehand gesture to the experimenter they were asked to rate their prior familiarity with the freehand gesture, give details of this familiarity as well as rate the fit of the freehand gesture to the task. Participants were asked the following questions for each of the 18 freehand gestures they were trained on.

Questionnaire

	(i) Please indicate how familiar you are with the gesture (1 is not familiar at all and 7 very familiar) 1 2 3 4 5 6 7 ***(i) (ii) From where you are familiar with it?*** ***(i) How well do you think the gesture matched the task (1 not well matched and 7 very well matched)*** 1 2 3 4 5 6 7

C.3.5 Learning Assessment Questionnaire - All Conditions

After the participant had correctly performed the freehand gesture they were asked to rate the fit of the freehand gesture to the task. Participants were asked the following question for each of the 18 freehand gestures they were tested on.

Questionnaire

	How well do you think the gesture matched the task (1 not well matched and 7 very well matched)						
	1	2	3	4	5	6	7

C.3.6 Transfer Questionnaire - All Conditions

After the participant had performed a freehand gesture they were asked to rate the fit of the freehand gesture to the task. Participants were asked the following question for each of the 36 new *Directed* and *Open Ended* user tasks presented.

Questionnaire

	How well do you think the gesture matched the task (1 not well matched and 7 very well matched)						
	1	2	3	4	5	6	7